# FINAL REPORT

# Metals and pH TMDLs for the Paint Creek Watershed, West Virginia

West Virginia Water Resources Institute
West Virginia University
Morgantown, WV

For:

West Virginia Department of Commerce,
Labor and Environmental Resources,
Department of Environmental Protection,
Division of Water Resources,
1201 Greenbrier Street,
Charleston, WV 25311-1088

And:

United States Environmental Protection Agency
Region 3
1650 Arch Street
Philadelphia, PA 19103-2029

September 2001

**Acknowledgements**

This TMDL study was conducted by West Virginia Water Resources Institute at West Virginia University for the West Virginia Department of Environmental Protection, Division of Water Resources under contact DEP10833. The West Virginia Water Resources Institute would like to thank Mary Beck, USEPA Region 3, David Montali, WVDEP Division of Water Resources, David Vandelinde and Tony Barnett, WVDEP Division of Mining and Reclamation for their assistance in the writing of this document. Sheila Vukovich and Greg Adolfson were also helpful in the writing of Appendix G.

## Table of Contents

## List of Figures

## List of Tables

## 1.0 Introduction

Section 303(d)(1)(A) of the Federal Clean Water Act (CWA) states:

> "Each state shall identify those waters within its boundaries for which the effluent limitations required by section 301(b)(1)(B) are not stringent enough to implement any water quality standards applicable to such waters. The State shall establish a priority ranking for such waters taking into account the severity of the pollution and the uses to be made of such waters."

Further, section 303(d)(1)(C) states:

> Each state shall establish for the waters identified in paragraph (1)(A) of this subsection, and in accordance with the priority ranking, the total maximum daily load, for those pollutants which the Administrator identifies under section 304(a)(2) as suitable for such calculations. Such load shall be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality.

Two main stem segments and sixteen tributaries have been placed on West Virginia's section 303(d) list of impacted waters (Table 1-1). The objective of this TMDL Report is to develop pH and metals TMDLs for the streams in the Paint Creek watershed impaired by mine drainage. Two main stem segments and fourteen tributaries are listed for the pollutants pH and/or metals with the impairment attributed to mine drainage. Three additional tributaries are listed for biological impairment. The causative pollutant(s) and source(s) of the biologically impaired streams are not identified.

## 1.1 Problem Understanding

Paint Creek, a tributary of the Kanawha River, flows in a northerly direction through parts of Raleigh, Fayette and Kanawha counties in south-central West Virginia (Figure 1-1) and has a drainage area of 318 $km^2$ (123 $mi^2$). For the past 90 years, surface and deep coal mines have operated in the watershed. Before the implementation of the West Virginia Surface Coal Mining and Reclamation Act (WVSCMRA) and Surface Mining Control and Reclamation Act (SMCRA), little consideration was given to the environmental degradation that resulted from these activities. Currently, the quality of Paint Creek and its tributaries are being negatively impacted by the acidic drainage from those mines that were abandoned prior to the environmental regulations. The environmental impact of this mine drainage is being manifested in depressed stream pH and elevated concentrations of iron, manganese and aluminum.

Sycamore Branch, Hickory Camp Branch and South Sand Branch are the Paint Creek tributaries that are listed as biologically impaired. Hickory Camp Branch is also listed for pH and metals with impairment attributed to mine drainage. Implementation of this TMDL should restore the biological integrity of Hickory Camp Branch. The biological impairment of South Sand Branch and Sycamore Branch cannot be attributed to active or historical mining activities. Further evaluation and TMDL development is needed to address these impaired waters.

Table 1-1. Paint Creek Watershed Segment on Section 303(d) list.

| Stream Segment Name | Segment ID | Length (miles) | Year Listed | Trout Stream | pH | Fe | Mn | Al | BC[1] |
|---|---|---|---|---|---|---|---|---|---|
| Jones Branch | K-65-C | 1.43 | 1996 | No | | X | X | X | |
| Packs Branch | K-65-DD | 3.80 | 1996 | No | | X | X | X | |
| Big Fork of Packs Branch | K-65-DD-2 | 1.24 | 1996 | No | | X | X | X | |
| Sycamore Branch[2] | K-65-L | 1.49 | 1998 | No | | | | | X |
| Ten Mile Fork[3] | K-65-M | 2.44 | 1996 | No | X | X | X | X | |
| Long Br. of Ten Mile Fork | K-65-M-1 | 1.43 | 1996 | No | X | X | X | X | |
| Hickory Camp Branch[4] | K-65-P | 3.80 | 1996 | No | X | X | X | X | X |
| Cedar Creek | K-65-Q | 1.20 | 1998 | No | X | | | | |
| Unnamed Tributary #1 | K-65-Q.3 | 0.36 | 1998 | No | X | X | X | X | |
| Unnamed Tributary #2 | K-65-Q.5 | 0.44 | 1998 | No | X | X | X | X | |
| Fifteen Mile Creek | K-65-R | 1.24 | 1996 | No | | X | X | X | |
| Spring Branch | K-65-S | 1.30 | 1998 | No | X | | | | |
| Skitter Creek | K-65-T | 1.48 | 1998 | No | | X | X | X | |
| Lykins Creek | K-65-W | 4.62 | 1996 | No | X | X | X | X | |
| Long Branch of Mossy Creek | K-65-Y-2 | 2.43 | 1996 | No | | X | X | X | |
| South Sand Branch[2] | K-65-HH-2 | 3.97 | 1998 | No | | | | | X |
| Paint Creek (Mouth - 16.8) | K-65 | 16.80 | 1996 | Partially | | | | X | |
| Paint Creek (MP 11.0 - 16.8) | K-65 | 5.80 | 1996 | Partially | X | | | | |

[1]Biological Criteria.
[2]Length of entire stream given.
[3]Corrected length of Ten Mile Fork from 303(d) list.
[4]Length of listed stream segment obtained from AMD portion of the 303(d) list.

Table 1-1. Paint Creek Watershed Segments on 303(d) list.

[1]Biological Criteria.
[2]Length of entire stream given.
[3]Corrected length of Ten Mile Fork from 303(d) list.
[4]Length of listed stream segment obtained from AMD portion of the 303(d) list.

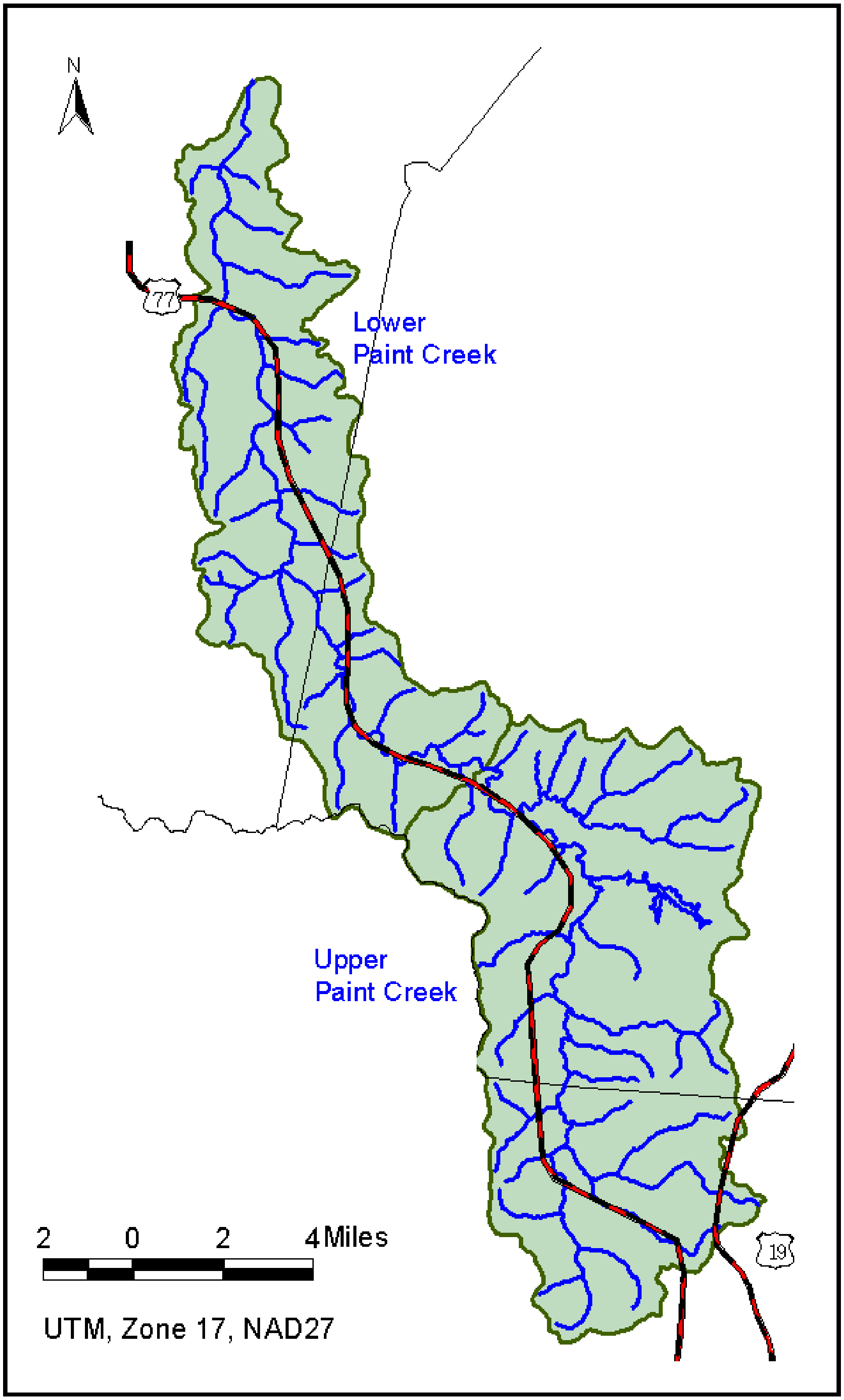



Figure 1-1. Paint Creek Watershed

## 2.0 Water Quality Standards

The State of West Virginia's *Requirements Governing Water Quality Standards* (WVWQS, 1999) have defined water quality criteria for surface waters as a numeric constituent concentration or a narrative statement representing a quality of water that supports a designated use or uses of the body of water. Aluminum, iron and manganese concentration and stream pH are given numeric criteria under the Aquatic Life and the Human Health use designation categories (Table 2-1). All listed stream segments in the Paint Creek watershed have been designated as having an Aquatic Life and a Human Health use (WVDEP, 1998a). The main stem of Paint Creek between Pax, WV, and Burnwell, WV, has also been identified as a trout stream (WVDNR, 2001). This segment must meet the Aquatic Life B2 criteria.

Table 2-1. Applicable West Virginia Water Quality Criteria.

| Pollutant | Use Designation | | | | |
|---|---|---|---|---|---|
| | Aquatic Life | | | | Human Health |
| | B1, B4 | | B2 | | |
| | Acute [a] | Chronic [b] | Acute [a] | Chronic [b] | A [c] |
| Total Aluminum, mg/L | 0.75 | - | 0.75 | - | - |
| Total Iron, mg/L | - | 1.50 | - | 0.50 | 1.50 |
| Manganese, mg/L | - | - | - | - | 1.00 |
| pH | No values below 6.0 or above 9.0. | | | | |

Source: WVWQS, 1999; B1 = Warm water fishery stream, B4 = Wetlands, B2 = Trout waters, A = Water supply, public.

[a] One-hour average concentration not to be exceeded more than once every three years on the average.

[b] Four-day average concentration not to be exceeded more than once every three years on the average.

[c] Not to exceed.

## 3.0 Source Assessment

This section examines and identifies the potential sources of acidity, aluminum, iron, and manganese in the Paint Creek watershed. Paint Creek watershed stream segments that are impaired due to depressed pH and elevated aluminum, iron and manganese concentrations are impaired by acidic mine drainage (AMD).

## 3.1 Acidic Mine Drainage

AMD forms when sulfide minerals are exposed to oxidizing conditions in coal and metal mining, highway construction, and other large-scale excavations. In coal mining regions, iron sulfides are predominately pyrite and marcasite ($FeS_2$). Upon exposure to $H_2O$ and $O_2$, sulfide minerals oxidize to form acidic, sulfate-rich drainage. Metal composition and concentration in AMD depend on the type and quantity of sulfide minerals present. The drainage quality emanating from underground mines or surface mine backfills is dependent on the amount of acid producing (sulfide) and alkaline (carbonate) minerals contained in the disturbed rock. In general, disturbing sulfide-rich and carbonate-poor rock produces acidic drainage and sulfide-poor and carbonate-rich rock produces alkaline drainage. Disturbed carbonate-rich rock can produce alkaline drainage even with significant sulfide concentrations.

The acidity in the AMD produced in coal mines is comprised of mineral acidity (Fe, Al, Mn) and $H^+$ acidity. Approximately 20,000 km (12,000 mi) of streams and rivers in the United States are degraded by AMD. About 90% of the AMD reaching streams originates in abandoned surface and deep mines. Since no company or individual is responsible for reclaiming abandoned mine lands (AML), little treatment of the drainage occurs and the contamination of surface and subsurface water resources continues unabated (Skousen, Sexstone and Ziemkiewicz, 2000).

The oxidation of iron disulfides and subsequent conversion to acidity occur through several reactions (Stumm & Morgan, 1970), which are detailed in Chapter 5 of Geidel and Caruccio (2000). If any of the processes represented by these equations are slowed or stopped, the generation of AMD is also slowed or ceases. Removal of air and/or water, two of the three principal reactants, from the system will stop pyrite oxidation. This occurs naturally when pyrite-bearing rocks are saturated. Because small amounts of pyrite are oxidized through weathering in undisturbed environments, only small amounts of acidity are generated, which are quickly diluted and neutralized by surrounding rocks. However, when large volumes of pyritic materials are exposed to oxidizing conditions, the pyrite reacts on a large scale and the reaction products (Fe, sulfate and acidity) are carried into surface and subsurface waters by runoff and infiltration. The generation of acidity is greatly increased by the oxidation of ferrous iron into ferric iron. This process is rather slow under abiotic (no life) conditions, but iron-oxidizing bacteria, *Thiobacillus ferrooxidans*, greatly increase the kinetic rate of this reaction (Waksman, 1922). The presence of the biotic catalysts from these bacteria can increase the overall generation of acidity by a factor of one million (Leathen et al., 1953).

## 3.2 Point Sources

Permitted discharges are point sources at discrete locations in the Paint Creek watershed and can be classified into two major categories: mining point sources and non-mining point sources. Identified non-mining point sources in the watershed include small sewage treatment facilities, small commercial facilities registered under an industrial stormwater general WV/NPDES permit, and construction sites registered under a construction stormwater general WV/NPDES permit. These sources do not discharge significant amounts of the pollutants of concern of this study and are not considered further. Mining point sources include various coal mining operations, as well as sandstone quarries, and are the focus of this report.

The WVDEP Office of Mining and Reclamation (OMR) regulates deep and surface coal mines and quarries and issues National Pollutant Discharge Elimination System (NPDES) permits for the discharges from mining operations. NPDES permits contain effluent limitations and/or self-monitoring requirements for the pollutants of concern of this TMDL. The results of self-monitoring are regularly reported to the WVDEP in Discharge Monitoring Reports (DMRs).

Additionally, OMR issues permits for mineral extraction, preparation, refuse disposal and ancillary operations pursuant to West Virginia Code Chapter 22 Article 3 and Article 4, respectively. Such permits are known as “Article 3” and “Article 4” permits. Multiple Article 3 and Article 4 permits can be associated with an individual NPDES Permit.

In this TMDL Report, NPDES Permit and outlet numbers are used to identify individual point sources. The primary advantage of organization by NPDES Permits is that the individual outlets (Figure 3-1) are located in WVDEP’s databases, whereas Article 3 and 4 permits are located by the reported latitude and longitude of the geographical center of mining operations. Effluent limits and DMR data are also available by NPDES outlet. The NPDES permit outlet locations and associated information facilitated model calibration, development of the baseline condition (See Section 6.2) and allocation model runs (See Section 6.4).

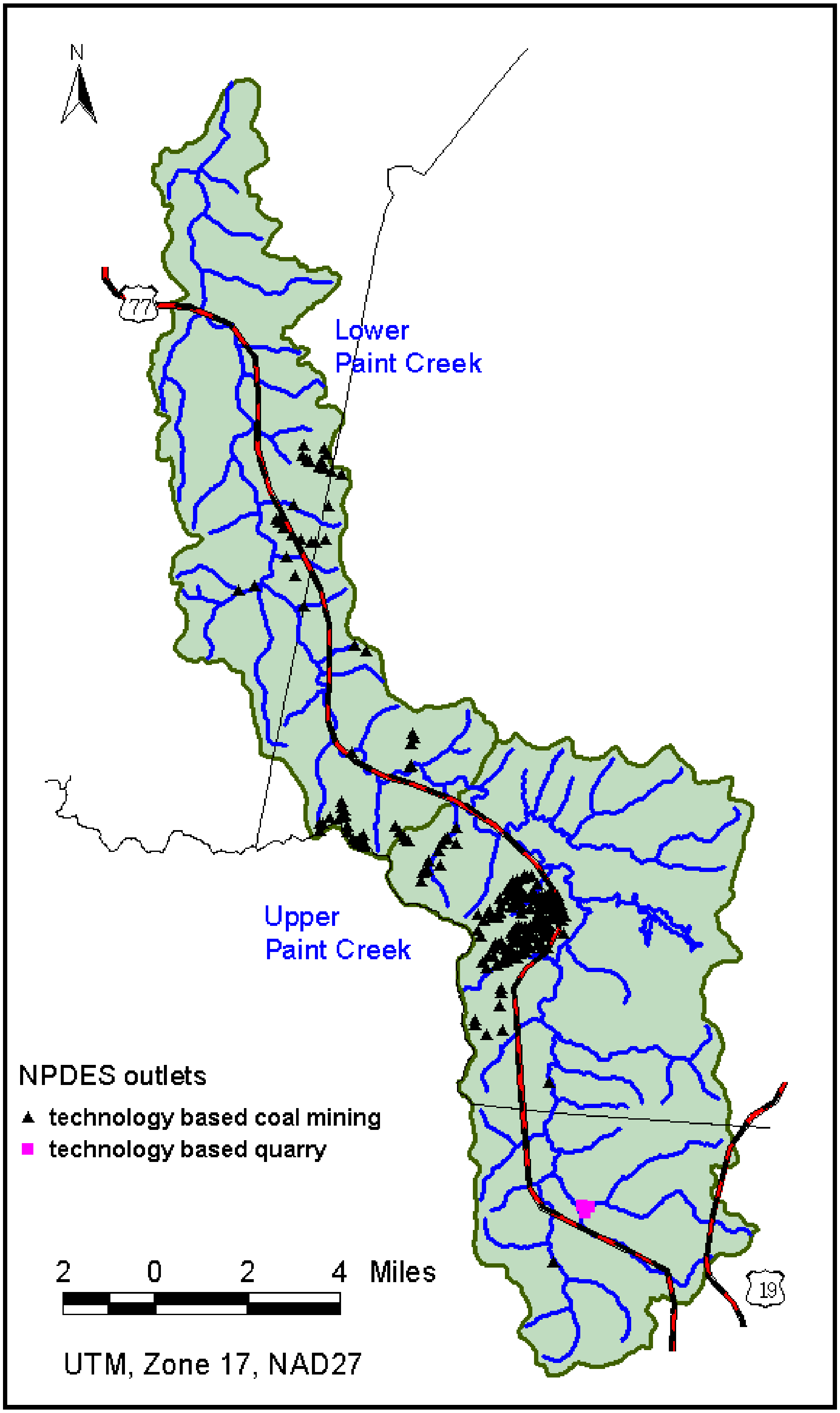



Figure 3-1. NPDES Permit types in the Paint Creek Watershed.

The WVDEP database information associated with Article 3 and Article 4 permits contains valuable information relative to the operational status of the mining activity. Facilities that have achieved "Phase 2 Release" status have performed reclamation to the point that treatment systems and drainage structures are removed. As such, those facilities were not considered in the baseline condition or in the allocation models. Table 3.1 describes the Article 3 / Article 4 status classifications. The association of Article 3 / Article 4 permit and operational status with NPDES permits was provided by WVDEP-OMR. Table A-1 in Appendix A presents the association between Article 3 / Article 4 permits and NPDES permits.

Table 3-1. Classifications of Article 3 and 4 Permit Status.

| Status Class | Description | TMDL Application |
|---|---|---|
| New | Newly issued permit, may or may not have commenced discharge. | Assumed to be discharging in accordance with NPDES effluent limitations in base condition and allocation runs. |
| Renewed | Active mining facility. | |
| Inactive | Currently inactive operation but could become active at any time. | |
| Phase I Released | Active mining has ceased, site has been re-graded and reseeded; treatment facilities and outlet structures remain. | |
| Phase II Released | Active mining has ceased; treatment facilities and discharge structures usually have been removed. If landowner desires ponds not be removed, one year of data demonstrates influent quality complies with effluent limitations. | Not considered as an existing source in the TMDLs. |
| Completely Released | Active mining has ceased; treatment facilities and discharge structures have been removed. | |
| Revoked | Bond forfeited, NPDES permit may be expired or revoked, highest potential impact to water quality. | Base condition loading determined by model. Considered non-point source loading in the TMDL. |

## 3.3 Non-point Sources

Non-point sources of acidity and metals also contribute to the environmental degradation of the Paint Creek watershed. The largest source of acidity and metals within the watershed consists of AMD from abandoned mine lands (AML). AML sites are those mines for which no company or individual is responsible for the quality or quantity of mine drainage. These mines were closed prior to the passage of the Surface Mining Control and Reclamation Act (SMCRA, 1977). Figure 3-4 is a map of the known non-point sources of AMD within the Paint Creek watershed. Bond forfeiture sites also represent mining non-point sources of acidity and metals. Because the little is known about the acidity and metals loading from non-point sources, the magnitude of these loads must be determined during the model calibration process.

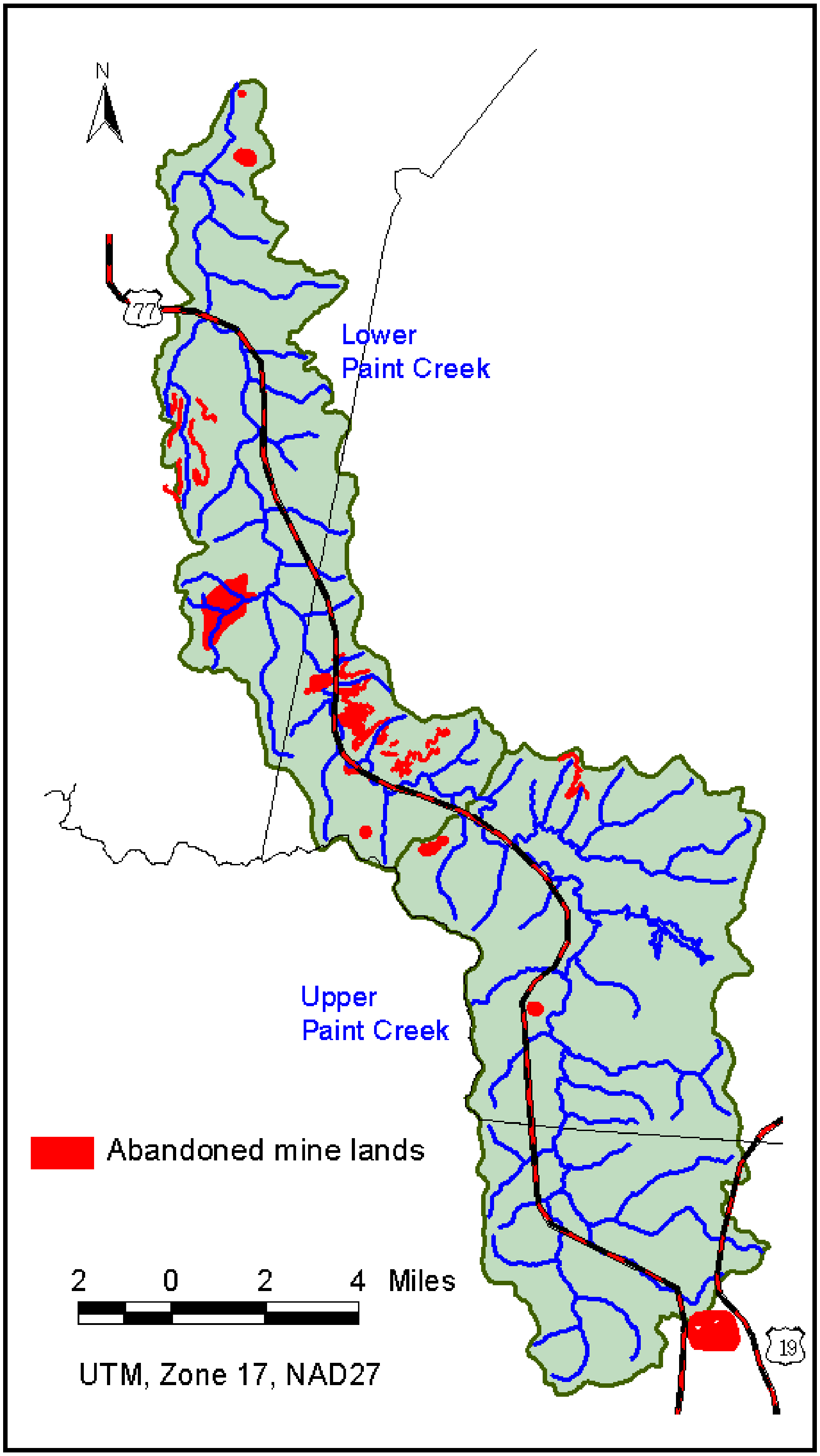



Figure 3-2. Known Mining NPS sites within the Paint Creek Watershed.

## 4.0 Technical Approach

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of TMDL development. It allows for evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain water quality responses to flow and loading conditions. The objective of this section is to present the approach taken to develop the linkage between sources and in-stream response for TMDL development in the Paint Creek watershed.

## 4.1 Model Framework Selection

Selection of the appropriate approach or modeling technique required consideration of the following:

- Expression of water quality criteria
- Dominant processes
- Scale of analysis

The relevant criteria for metals and pH were presented in Section 2. Numeric criteria, such as those applicable here, require evaluation of magnitude, frequency, and duration of appropriate water quality parameters. For metals, the West Virginia criteria are expressed as total metals. This dictates that the methodology predict the total metals concentration in the water column of the receiving water. The criteria for iron and aluminum are expressed as a concentration that cannot be exceeded at a rate greater than the specified exceedance frequency (e.g., not to exceed more than once every 3 years on average). Acute standards (e.g., aluminum, manganese and pH) typically require evaluation over short time periods and violations may occur under variable flow conditions. Chronic criteria (e.g., iron) require the evaluation of the response over a four-day averaging period. The approach or modeling technique must permit representation of in-stream concentrations under a variety of flow conditions, in order to evaluate critical periods for comparison to chronic and acute criteria.

The approach must also consider the dominant processes regarding pollutant loadings and in-stream fate. For the Paint Creek watershed, primary sources contributing to metals and pH impairments include an array of non-permitted (non-point) sources as well as permitted (point) sources. Unlike non-permitted discharges, permitted discharges are controlled by permit limits.

Key in-stream factors that must be considered include advection, dispersion, reaction and loading of simulated constituents. Significant chemical processes include: oxidation, precipitation and sedimentation. In addition to advection and dispersion, significant physical processes include stream reaeration and meteorological heating.

Scale of analysis must also be considered in the selection of the overall approach. The approach should have the capability to evaluate watersheds at multiple scales, particularly those of a few hundred acres in size. The listed waters in the Paint Creek watershed range from small streams to the main stem of the river. Selection of scale should be sensitive to locations of key features, such as abandoned mines and point source discharges. At the larger watershed scale, stream segments are lumped into subwatersheds for practical representation of the system, commensurate with the available data. Occasionally, there are site specific and localized acute problems, which may require more detailed segmentation or definition of detailed modeling grids.

Based on the considerations described above, analysis of the quality and quantity of hydrologic and water quality monitoring data, review of the literature and past pH and metals modeling experience, the source-response linkage in the Paint Creek watershed is represented with the Total Acidic Mine Drainage Loading (TAMDL) computer program. TAMDL was designed to simulate the stream transport, reaction and loading of those water quality constituents related to AMD. The Paint Creek TAMDL model and associated support software form a modeling system capable of representing loading from non-point and point sources found in the watershed and simulating in-stream processes.

## 4.2 Total Acidic Mine Drainage (TAMDL) Overview

The computer program TAMDL is designed to simulate those aspects of a watershed's stream water quality that are affected by acidic mine drainage. The current version of TAMDL simulates water temperature, net acidity, proton activity (pH), ferrous iron, ferric iron, manganese, aluminum and dissolved oxygen. Water quality conditions are simulated by numerically solving the one dimensional advection, dispersion, loading and reaction partial differential equation for each of these constituents. A detailed description of the theoretical basis of the TAMDL program is presented in Appendix B.

## 4.3 Model Configuration

The Paint Creek TAMDL model was configured by dividing the watershed into a series of hydrologically connected sub-watersheds and assembling the input data for each of the sub-watersheds. During a model simulation, TAMDL solves the governing partial differential equation for the stream segment in each sub-watershed. The upstream boundary conditions for the lower sub-watershed models are defined by the results generated for the upper sub-watersheds. Simulated constituents include: aluminum, ferric iron, manganese, net acidity and pH. The key components of the TAMDL model are described in the following sections.

### 4.3.1 Watershed Subdivision

To represent watershed loadings and the resulting concentrations of acidity and metals, the Paint Creek watershed was divided into 62 sub-watersheds. The stream segments simulated in each of these sub-watersheds are presented in Figure 4-1 and divided by hydrologic boundaries. The division was based on digital elevation data, stream connectivity from EPA's Version 3 Reach File and the locations of WVDEP-SRG water quality sample collection stations. The TAMDL model was calibrated to each of the WVDEP-SRG stations. The division was performed with the assistance of the Watershed Characterization and Modeling System (WCMS) program developed by the National Resources Analysis Center (NRAC) at West Virginia University. The Paint Creek TAMDL model sub-watersheds are shown in Figure 4-2. The stream names corresponding to the TAMDL model sub-watersheds are listed in Table 4-1. The technical capabilities of WCMS are outlined in Fletcher and Strager (2000).

WCMS was developed to bring spatial data and water quality modeling to the desktop of WVDEP personnel and is a customized ArcView GIS interface that combines a wide variety of spatial data layers and water quality modeling components for meeting common WVDEP tasks. Running within ArcView 3x it provides desktop mapping and analysis capabilities for the entire state of West Virginia (Fletcher and Strager, 2000).

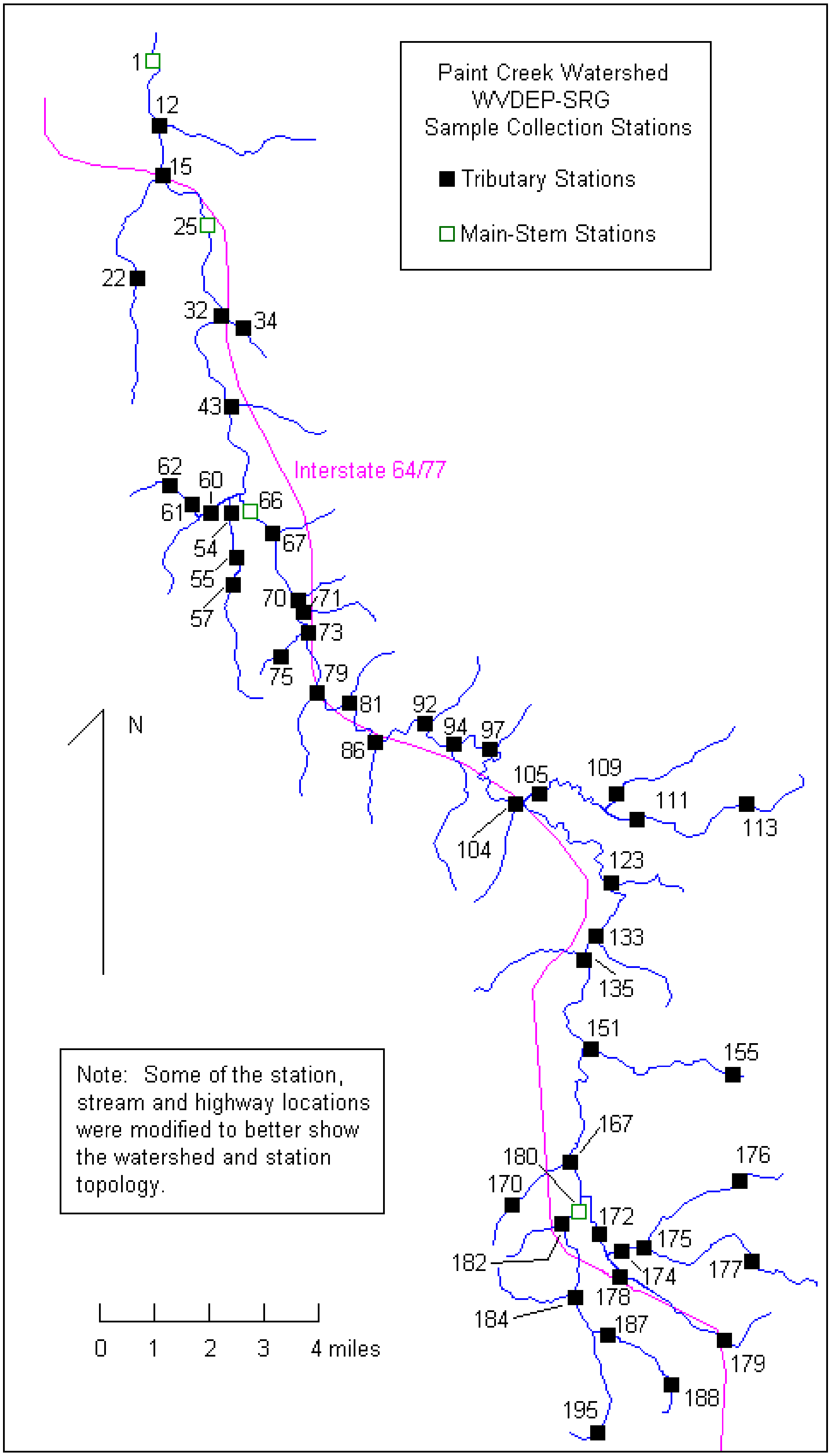



Figure 4-1. Domain of the Sub-models within the Paint Creek TAMDL Model.


Figure 4-2. Paint Creek TAMDL Model Sub-watersheds.

Table 4-1. Paint Creek Stream Names and Sub-watershed Numbers.

| Stream Name | Sub-watershed Number |
|---|---|
| Paint Creek below Banner Hollow | 1 |
| Banner Hollow | 2 |
| Paint Creek above Banner Hollow and below Fourmile Fork | 3 |
| Fourmile Fork | 4 |
| Paint Creek above Fourmile Fork and below Ash Branch | 5 |
| Ash Branch | 6 |
| Paint Creek above Ash Branch and below Toms Branch | 7 |
| Toms Branch | 8 |
| Paint Creek above Toms Branch and below Tenmile Branch | 9 |
| Long Branch | 10 |
| Tenmile Branch above Long Branch and below Unnamed Tributary | 11 |
| Unnamed Tributary of Tenmile Branch | 12 |
| Tenmile Branch above Unnamed Tributary | 13 |
| Paint Creek above Tenmile Branch and below Laurel Branch | 14 |
| Laurel Branch | 15 |
| Paint Creek above Laurel Branch and below Unnamed Branch | 16 |
| Unnamed Branch of Paint Creek | 17 |
| Paint Creek above Unnamed Branch and below Hickory Camp Branch | 18 |
| Hickory Camp Branch | 19 |
| Paint Creek above Hickory Camp Branch and below Cedar Creek | 20 |
| Cedar Creek | 21 |
| Paint Creek above Cedar Creek and below Fifteenmile Creek | 22 |
| Fifteenmile Creek | 23 |
| Paint Creek above Fifteenmile Creek and below Unnamed Tributary | 24 |
| Spring Branch | 25 |
| Paint Creek above Unnamed Tributary and below Skitter Creek | 26 |
| Skitter Creek | 27 |
| Paint Creek above Skitter Creek and below Rattlesnake Run | 28 |
| Rattlesnake Run | 29 |
| Paint Creek above Rattlesnake Run and below Milburn Creek | 30 |
| Milburn Creek | 31 |
| Paint Creek above Milburn Creek and below Lykins Creek | 32 |
| Lykins Creek | 33 |
| Paint Creek above Lykins Creek and below Bishop Fork | 34 |
| Bishop Fork | 35 |
| Paint Creek above Bishop Fork and below Mossy Creek | 36 |
| Mossy Creek below Lick Fork | 37 |
| Lick Fork | 38 |
| Mossy Creek above Lick Fork | 39 |
| Paint Creek above Mossy Creek and below Plum Orchard Creek | 40 |
| Plum Orchard Creek | 41 |
| Paint Creek above Plum Orchard Creek and below Horse Creek | 42 |
| Horse Creek | 43 |
| Paint Creek above Horse Creek and below Town Creek | 44 |
| Town Creek | 45 |
| Paint Creek above Town Creek and below Packs Branch | 46 |
| Packs Branch | 47 |
| Paint Creek above Packs Branch and below Dixons Branch | 48 |
| Dixons Branch | 49 |
| Paint Creek above Dixons Branch and below Sand Branch | 50 |
| Sand Branch below North Sand Branch | 51 |
| North Sand Branch below Maple Fork | 52 |

| Stream Name | Sub-watershed Number |
|---|---|
| Maple Fork | 53 |
| North Sand Branch above Maple Fork | 54 |
| South Sand Branch | 55 |
| Paint Creek above Sand Branch and below Laurel Branch | 56 |
| Laurel Branch | 57 |
| Paint Creek above Laurel Branch and below Davis Branch | 58 |
| Davis Branch | 59 |
| Paint Creek above Davis Branch and below Lefthand Fork | 60 |
| Lefthand Fork | 61 |
| Paint Creek above Lefthand Fork | 62 |

### 4.3.2 Meteorological Data

Meteorological data was not a critical component of the Paint Creek watershed TAMDL model because some sources of AMD release more acid and metals during precipitation events and some do not. However, the oxidation and precipitation reactions simulated by the model have some dependence on temperature and dissolved oxygen concentration, so mean monthly temperature and wind speed data from the National Weather Service station at Charleston, WV was included in the model. While TAMDL does have the capability to simulate stream reaeration due to fluid motion, numerical experiments have indicated that the simulation of reaeration is impractical when the mean depth of the stream is less than one meter. Because the Paint Creek TAMDL model must simulate water quality conditions in a variety of flow conditions, it was decided that the model would assume that the stream was saturated with dissolved oxygen. Given the rugged topography of the watershed, this assumption is reasonable.

### 4.3.3 Point Source Representation

Point sources in the TAMDL model are represented as an acid and/or metal load being applied to a particular finite difference model node in a particular sub-watershed for a specified period. For matching model results to historical data, which is described in more detail in the Model Calibration section, it was necessary to represent the point sources using available historical data. If Discharge Monitoring Report (DMR) data are available, permitted mines are represented in the model using average flows and pollutant loads. The DMR data includes monthly averages and maximums for flow, pH, aluminum, iron, and manganese. The monthly average metals concentrations were multiplied by the discharge flows to estimate average loadings for these point sources.

### 4.3.4 Non-point Source Representation

Since the quality of drainage from both surface and deep mines depends upon the nature of the minerals in contact with the water (Skousen, Sexstone and Ziemkiewicz, 2000), observed acidity and metal concentrations will depend upon the flow path of the drainage as it reaches the receiving stream. The geometry of this drainage flow path is essentially a random variable independent of the quantity of mine drainage. This is illustrated by Figure 4-3, which is a scatter plot of reported iron concentrations versus reported discharge rates for permitted mine outlets in the Paint Creek watershed.

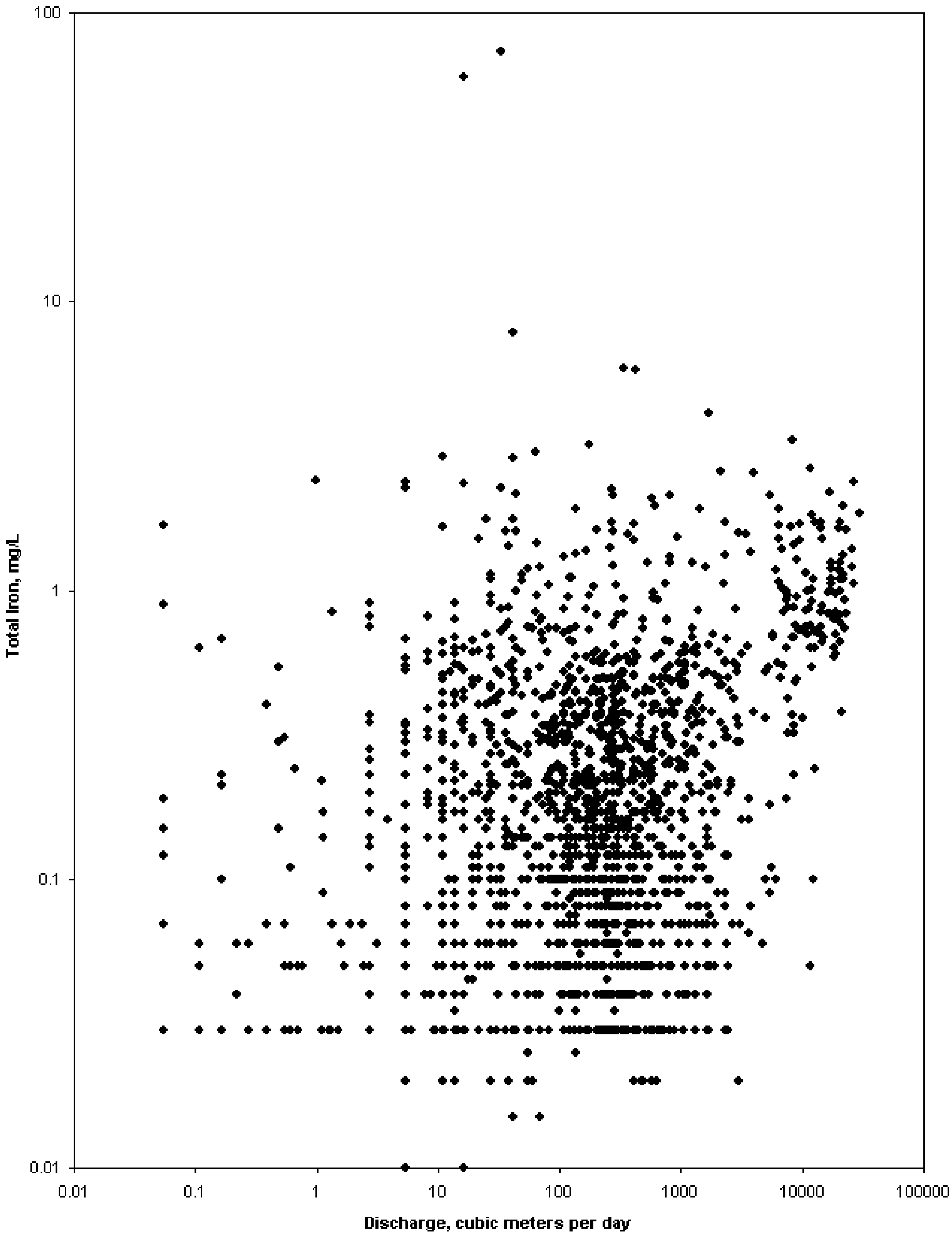



Figure 4-3. Iron Concentration vs. Discharge Rate from Paint Creek DMR data.

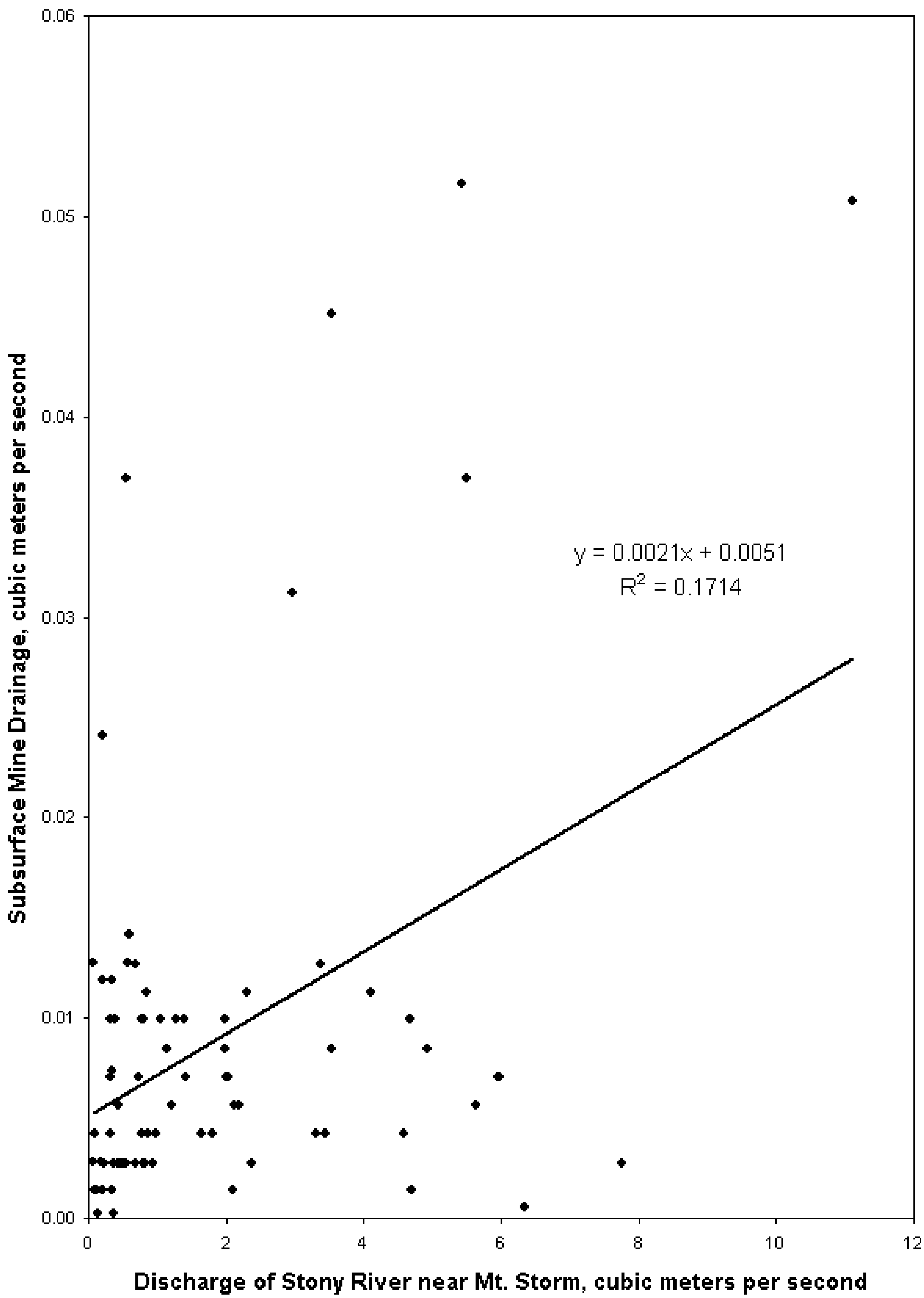



Figure 4-4. Deep Mine Drainage Discharge Rate versus Stony River Stream Discharge Rate near Mt. Storm, WV.

Because of Darcy's law, the lag time between precipitation events and increases in the mine drainage discharge rate is inversely proportional to the length of the flow path and the soil's hydraulic conductivity along the flow path. Therefore, the degree to which the mine drainage discharge rate is driven by individual precipitation events is a function of the geometry of the drainage flow path. This lack of correlation between mine effluent quality and discharge rate was also observed with the DMR concentrations for aluminum and manganese and pH.

Figure 4-4 illustrates the random nature of this drainage flow path for the discharge from a deep mine in Grant County, West Virginia. If the quantity of deep mine drainage was directly proportional to the precipitation rate, then it would be possible correlate deep mine drainage and stream discharge rates. If the drainage flow path was consistent from one rainfall event to another, then it would have been possible to achieve a correlation between mine drainage and weekly or monthly averaged stream discharge rates. The extremely low correlation coefficient observed with the daily average stream data, $R^2 = 0.1714$, was actually greater than the correlation observed with the weekly and monthly averaged data, 0.1509 and 0.1405, respectively. In the absence of similar data for any of the deep mines in the Paint Creek watershed, this report will assume that the quantity of deep mine drainage is not directly proportional to either the short-term or long-term precipitation rate.

While the quantity of drainage from surface mines may, in some instances, be directly proportional to the precipitation rate, distinguishing between abandoned surface and deep mined areas on existing GIS coverages is difficult. Therefore, non-point sources are represented in the Paint Creek TAMDL model in the same manner as point sources. Unlike point sources, non-point sources of mine drainage in the Paint Creek watershed are not regularly sampled by either regulatory agencies or mine operators. With the exception of a limited amount of data for the Ten Mile Fork, Long Branch and Cedar Creek sub-watersheds, water quality data from AML portals was not available. Consequently, the determination of the magnitude of acid and metal loads from these sources was made during the calibration of the model.

### 4.3.5 Stream Representation

Modeling subwatersheds and calibrating hydrologic and water quality model components required simulating the transport of both water and pollutants through streams. Each subwatershed was represented with a single stream with uniform geometric and hydraulic characteristics. Stream segments were identified using EPA's RF3 stream coverage within the program WCMS. TAMDL simulates stream flow by assuming uniform flow conditions. Required stream data includes slope, Manning's roughness coefficient, and mean channel dimensions. Stream slopes and lengths were calculated from the DEM data and the RF3 stream coverage available in WCMS. Manning's roughness coefficient and stream dimensions were estimated from observed data.

### 4.3.6 Hydrologic Representation

Hydrologic processes were simulated in the model by distributing the daily stream flow measured at a local gauging station according to sub-watershed drainage area. The flow hydrograph for each tributary sub-watershed was calculated by multiplying the daily flow observed at the station by the ratio of the sub-watershed drainage area and the gauging station drainage area. This method is more accurate when the gauging station and the tributary sub-watershed have similar drainage areas and runoff characteristics. The flow hydrographs for downstream sub-watersheds was calculated by summing the flow hydrographs of the adjacent upstream sub-watersheds. Because the model employed daily flow hydrographs and the small size of the sub-watersheds, hydrologic routing techniques were not employed.

Unfortunately, no USGS stations were located within the Paint Creek watershed; the closest USGS station was at site number 03200500 on the Coal River at Tornado, WV. The USGS Coal River station at Tornado, WV has a drainage area of 1260 $km^2$ (862 $mi^2$) and a period of record extending back to July 1, 1908. The Coal River station was selected because of its relative proximity to the watershed (05050009 Coal) and its rather long period of record.

Since there was very little hydrologic data directly measured within the watershed to calibrate model hydrology, it was decided that the application of a more sophisticated hydrologic model would not improve the ability of the model to simulate water quality conditions.

### 4.3.7 Pollutant Representation

In addition to flow, the Paint Creek watershed TAMDL model simulated four water quality constituents: pH, net acidity, iron, manganese, and aluminum. Stream pH was calculated by TAMDL with an empirical constitutive relationship from the net acidity of the stream. The loading contributions of net acidity, iron, manganese, and aluminum from different non-point and point sources were represented in the TAMDL model as sources applied to individual finite difference nodes. Discharge data from the DMRs for individual NPDES permits were used to calculate the point source contribution of these constituents. The contributions of these constituents from non-point sources were estimated as part of the model calibration process.

## 4.4 Model Calibration

After the model was configured, calibration was performed at multiple locations throughout the Paint Creek watershed. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. Because no USGS gauging stations are located with the watershed, model calibration focused on water quality.

Observed water quality data were obtained from EPA's STORET database as well as from the Stream Restoration Group (WVDEP-SRG). Data from both sources were obtained through WVDEP. Normally significant amounts of time-varying monitoring data are necessary to calibrate any water quality model. A total of 210 stream water quality data points was available for model calibration and are listed in Appendix C. Water quality data from samples collected from abandoned mine seeps were used to estimate some of the mining non-point source loads and are listed in Appendix C. Included in Appendix C are the results of a violation analysis performed on the observed stream water quality data.

Modeled versus observed in-stream concentrations were directly compared during model calibration. The water quality calibration consisted of executing the watershed model, comparing water quality time series output to available water quality observation data, and adjusting water quality parameters within a reasonable range. Results of the water quality calibration are presented in Appendix D.

# 5.0 Allocation Analysis

A TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving water quality standards. TMDLs can be expressed in terms of mass per time or by other appropriate measures. TMDLs are comprised of the sum of individual wasteload allocations (WLA) point sources, load allocations (LA) for non-point sources, and natural background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving stream. Conceptually, this definition is denoted by the following equation.

$$TMDL = WLA + LA + MOS$$

In order to develop aluminum, iron, manganese, and pH TMDLs for each of the streams in the Paint Creek watershed, the following approach was taken:

1. Define TMDL endpoints.
2. Simulate baseline conditions.

3. Assess source loading alternatives.
4. Determine the TMDL and source allocations.

## 5.1 TMDL Endpoints

TMDL endpoints represent the in-stream water quality targets used in quantifying TMDLs and their individual components. Different endpoints are necessary for each impairment type (i.e., aluminum, iron, manganese, and pH). The State of West Virginia's numeric water quality criteria for aluminum, iron, manganese, and pH and an implicit margin of safety were used to identify endpoints for TMDL development.

The TMDL endpoint for aluminum was selected as 0.7125 mg/L (based on the 0.75 mg/L criteria for aquatic life minus a 5% MOS). The iron endpoint was selected either as 0.475 mg/L (based on the 0.5 mg/L criteria for aquatic life-trout waters minus a 5% MOS) or 1.425 mg/L (based on the 1.5 mg/L criteria for aquatic life minus a 5% MOS). The manganese endpoint was selected as 0.95 mg/L (based on the 1.0 mg/L criteria for human health minus a 5% MOS). The water quality criterion for pH requires it to be between 6.0 and 9.0 standard units (SU), inclusive. Instead of using a percentage-based margin of safety for pH, this study used a MOS of 0.5 SU. Therefore, the TMDL endpoints for pH are 6.5 SU and 8.5 SU. The magnitudes of these margins of safety are based upon the expected reliability of the TMDL determination, in this case modeling, effort.

In the case of acid mine drainage, pH, is not a good indicator of stream acidity and can be a misleading characteristic. Water with a circum-neutral pH (~7) but containing elevated concentrations of dissolved ferrous ions can become acidic after oxidation of the ferrous iron. Therefore, a more practical approach to meeting the water standards of pH is to use the net acidity of the stream as a surrogate for pH. The net acidity of a solution is the solution's total acidity minus the total alkalinity and is related to the stream's pH in TAMDL with an empirical constitutive relationship. TAMDL expresses a stream net acidity in terms of the concentration of calcium carbonate required to neutralize the stream (i.e., mg of calcium carbonate equivalents per liter of water). The procedure by which TAMDL uses net acidity as a surrogate for pH is explained more completely in the documentation of the TAMDL computer program in Appendix B.

Components of the TMDLs for aluminum, iron, and manganese are presented in terms of mass per unit time in this report. For pH, this report presents the TMDL in terms of net acidity loading. When the net acidity load is positive, it is defined as the mass of calcium carbonate needed to neutralize the acidity per unit time. When it is negative, it is defined as the alkalinity equivalent to the mass of calcium carbonate per unit time multiplied by negative one.

## 5.2 Baseline Conditions

The calibrated model provided the basis for performing the allocation analysis. The first step in this analysis involved simulation of baseline conditions. Baseline conditions represent existing non-point source loading conditions and permitted point source discharge conditions. The baseline conditions allow for an evaluation of in-stream water quality under the "worst currently allowable" scenario.

The model was run for baseline conditions for the period October 1, 1992 through September 30, 1999. Predicted in-stream pH, instantaneous concentrations of aluminum and manganese, and four-day averaged iron concentration for the streams in the Paint Creek watershed were compared directly to the TMDL endpoints. This comparison allowed evaluation of the expected magnitude and frequency of exceedances under a range of hydrologic and environmental conditions, including dry periods, wet periods, and average periods. This simulation period also bracketed the observed water quality and hydrologic data set.

The baseline loads from permitted mine outlets were estimated by multiplying the concentrations presented in Table 5-1 by the estimated discharge flow rate. For iron and manganese, the concentrations present in Table 5-1 represent the wasteload allocations associated with existing permit limits. They were determine through a back-calculation procedure using the limitation development principles of EPA's *Technical Support Document for Water Quality Based Toxics Control*. Although technology-based WV/NPDES Permits do not contain effluent aluminum concentration limits, more than 99.5% of observed effluent aluminum concentrations are less than value listed in Table 5-1. As such, the concentration is a reasonable representation of the aluminum wasteload allocation that is associated with existing permits. Figure 5-1 is a plot of the reported effluent aluminum concentration from Paint Creek DMRs during the simulation period of the baseline conditions model.

Table 5-1. Metals concentrations used in Representing Mine Discharge Loads.

| Pollutant | Technology-based Permit Limits | Water Quality-based Permit Limits |
|---|---|---|
| Aluminum | 4.3 mg/L* | 0.75 mg/L |
| Iron | 3.2 mg/L | 1.5 mg/L, 0.5 mg/L (trout waters) |
| Manganese | 2.0 mg/L | 1.0 mg/L |

*WVDEP technology-based mining permits require only the reporting of aluminum concentration.

The discharge flow rates from permitted mining outlets were estimated using one of two methods. If the outlet had observed DMR discharge data, then that data was used to calculate the average discharge rate for each calendar month of the simulation period. If the outlet had no DMR data for a particular month, then the annual average discharge was assigned to that month's discharge rate.

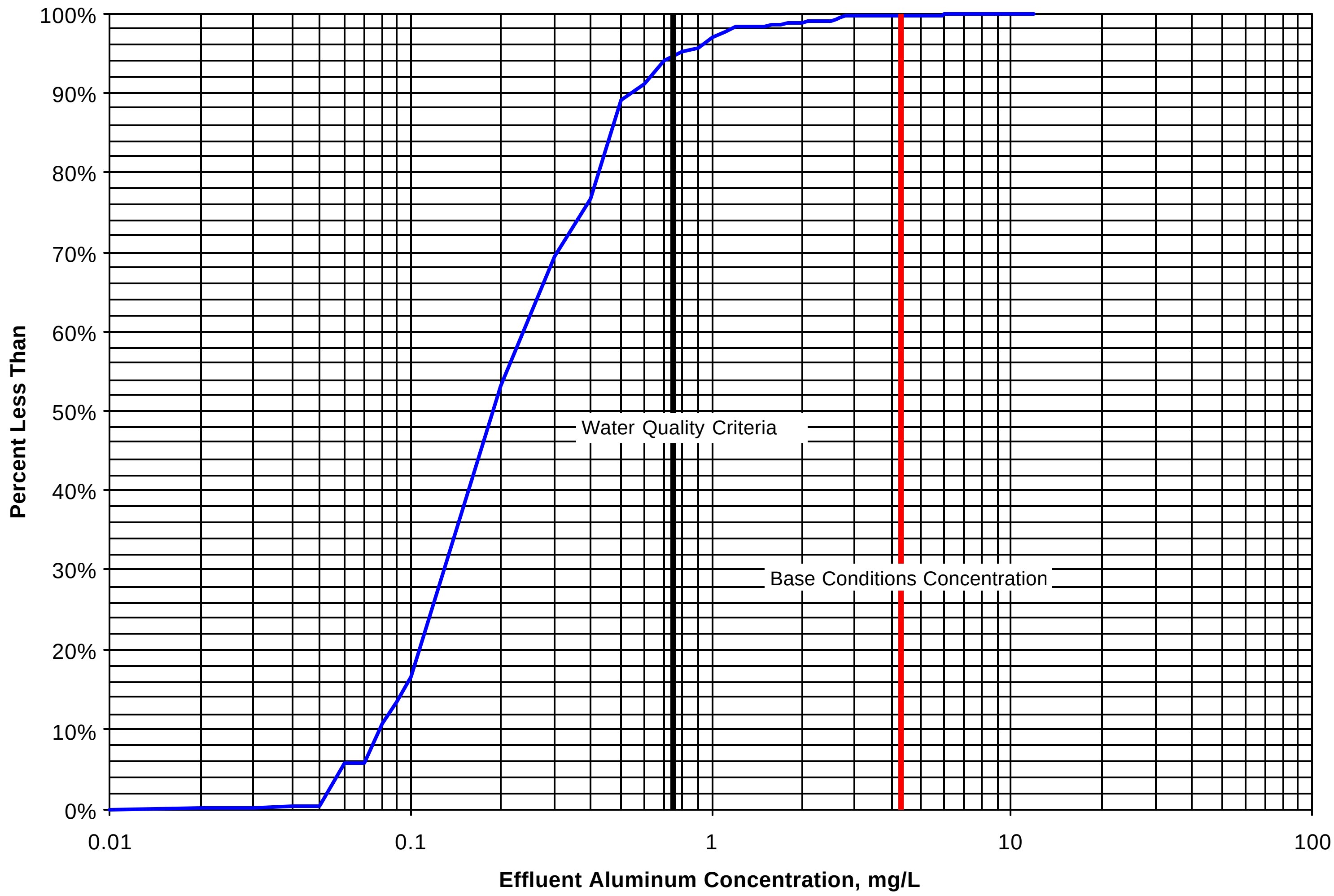



Figure 5-1.  Cumulative Probability Distribution of Reported Effluent Aluminum Concentrations in Paint Creek Watershed.

If DMR discharge data were not available, then WCMS program was used to estimate the disturbed area of the mine outlet and the surface drainage rate for a stream near the mine outlet. Because the surface drainage rate (mean stream flow rate per drainage area) does vary by season, the average surface drainage rate for each calendar month was obtained from WCMS. Hydrologists familiar with the drainage rates from mines in West Virginia estimate that the disturbed area of a mining operation will discharge more water as an undisturbed area in a watershed. The monthly average mine discharge rate for the outlet was estimated by multiplying the product of the disturbed area of the outlet and the monthly average surface drainage rate for the watershed by a factor of 2.

While this latter method of estimating the monthly average discharge from a mine outlet is subject to errors introduced by the estimate of disturbed area and drainage rate, a more precise analysis would involve a detailed examination of the permit application for each mine in the watershed and was deemed to be impractical for this study. Estimates of mine outlet discharge are not normally required in mining permit applications.

## 5.3 Source Loading Alternatives

Simulation of baseline conditions provided the basis for evaluating each stream's response to variations in source contributions under virtually all conditions. This sensitivity analysis gave insight into the dominant sources and how potential decreases in loads would affect in-stream pH and metals concentrations. For example, loading contributions from abandoned mines, permitted facilities, and other non-point sources were individually adjusted and in-stream concentrations were observed.

Multiple scenarios were run for the impaired streams. Successful scenarios were those that achieved the TMDL endpoints under all conditions for pH, aluminum, iron, and manganese (through comparison of model results for the entire seven-year simulation period). A scenario would be judged unsuccessful, if exceedances in any of these parameters occurred more frequently than is permitted by the water quality standards. Model output was sampled in approximately one-day intervals for these assessments. In general, loads contributed by mines with revoked permits and abandoned mines were reduced first, because they generally had the greatest impact on in-stream water quality. If additional load reductions were required to meet the TMDL endpoints, then reductions were made in point source (permitted) contributions.

The general allocation philosophy used in this TMDL is further described as follows:

1. Pollutant reductions were not required of non-mining point or non-point sources. Non-mining point sources in this watershed do not discharge significant amounts of acidity, aluminum, iron and manganese. Unlike some watersheds in West Virginia, stream sediments in the Paint Creek watershed do not introduce significant amounts of aluminum to stream waters. While the research presented by Watts, Hinkle and Griffitts (1994) indicate that sediments in the main stem of Paint Creek contain up to 6.22% aluminum, no correlation between observed aluminum concentration and stream flow or total suspended solids concentration was found. In the absence of other sources, the pollutants contributed by non-mining non-point sources (forest, agriculture, urban, sediments) do not cause water quality criteria violation.

2. Pollutant reductions of mining non-point sources (revoked permits and AML sites) were required first, to the extent necessary to achieve in-stream compliance.

3. Pollutant reductions from mining point sources were required only if mining non-point sources are not present in the subwatershed, or if the reduction of existing mining non-point sources was inadequate to achieve in-stream compliance.

This methodology ensures water quality criteria compliance in all streams in the watershed, targets pollutant reductions from the primary causative sources of impairment, and minimizes the impact to existing point sources in the watershed.

For most of the Paint Creek sub-watersheds, it was possible to bring the stream into compliance with the water quality standards by making reasonable reductions in the pollutant loads from mining non-point sources or by making reductions in the effluent concentration limits from certain mining point sources. A reasonably achievable reduction of mining non-point sources is defined as being the reduction in loading required to bring metal concentrations down to a level that would be present if mining non-point sources were releasing water in accordance with technology-based limits.

A similar criteria for the reasonable reduction of the acid load from non-point sources was not adopted because WVDEP requires that the effluent from outlets with either technology-based or water quality limits be circum-neutral ($6.0 \leq pH \leq 9.0$). Because the lower limit of this range corresponds to a such a small level of net acidity, the uncertainty in calculating the reasonable acid load minimum exceed the magnitude of the acid load. Therefore this TMDL assumes that a complete reduction of the acid load from an AML site to be reasonable. While WVDEP does not restrict the effluent aluminum concentration from outlets with a technology-based limit, the reported aluminum effluent concentrations for mine outlets in the Paint Creek watershed, as shown in Figure 5-1, indicate that the water quality standard, 0.75 mg/L, is a reasonably achievable reduction in concentration. The required reductions in load from mining non-point sources for each sub-watershed are given in Appendix F.

## 5.4 TMDLs and Source Allocations

A top-down methodology was followed to develop the TMDLs and allocate loads to sources. Headwaters and tributaries were analyzed first, because their impact frequently had a profound effect on downstream water quality. In impaired subwatersheds, loading contributions were reduced to the extent necessary to ensure compliance with in-stream criteria, and the loading associated with that condition was transferred to downstream subwatersheds. Conversely, where the model indicated that the baseline condition was compliant with water quality criteria, the loading associated with the baseline condition was transferred to downstream subwatersheds. The required headwater reductions often led to downstream water quality improvements, effectively decreasing necessary loading reductions from downstream sources.

In some situations, reductions in sources contributing to stream segments not included on the 303(d) list have been determined necessary to ensure universal compliance with water quality criteria in the watershed. The listed and non-listed stream segments requiring reduction in acid and metal loads is presented in Table C3 of Appendix C. Recent water quality data is not available for all streams in the watershed and the model is a technical tool available to determine if a particular permit is protective of water quality criteria. Other situations have been encountered where recent water quality data indicates that a particular stream segment is not impaired, yet the TMDL imposes point source wasteload allocations that represent a reduction of existing permit limitations. Certain permit holders are currently achieving discharge quality better than what is required by their permit may need to maintain such improved performance in order for the receiving water to consistently meet standards. The Paint Creek TMDLs for pH, aluminum, iron and manganese are listed in Tables 5-2, 5-3, 5-4 and 5-5, respectively. Sub-watersheds containing streams that have been placed on the 303(d) list are shown in bold type. Therefore, the rows in Table 5-2 which are shown in bold type correspond to stream segments which have been placed on the 303(d) list for pH, and the rows in Table 5-3 which are shown in bold type represent stream segments which are listed for aluminum. Tables 5-4 and 5-5 have bold rows for those stream segments listed for iron and manganese, respectively.

### 5.4.1 Wasteload Allocations

The wasteload allocations for aluminum, iron, and manganese are expressed in terms of a concentration within the ranges listed in Table 5-6. No wasteload allocation was necessary for acidity because the allowable technology-based limits for pH are the same as the water quality limits. The minimum range in Table 5-6 reflects the in-stream water quality criteria, and the maximum was derived from existing technology-based permits using the procedures of the EPA's *Technical Support Document for Water Quality-based Toxics Control* (USEPA, 1991). The wasteload allocations for all NPDES outlets in the Paint Creek watershed are listed in Appendix E.

Table 5-2. pH TMDL for each of the Paint Creek Sub-Watersheds.

| SWS | WLA, Mg/yr $CaCO_3$ equivalents | LA, Mg/yr $CaCO_3$ equivalents | Upstream Contribution, Mg/yr $CaCO_3$ equivalents | TMDL, Mg/yr $CaCO_3$ equivalents | Baseline NPS Load, Mg/yr $CaCO_3$ equivalents | Relative NPS Load Reduction |
|---|---|---|---|---|---|---|
| 1 | 0.0000 | 0.0000 | 16.1713 | 16.1713 | 0.0000 | 0.0000% |
| 2 | 0.0000 | -26.8459 | 0.0000 | -26.8459 | -26.8459 | 0.0000% |
| 3 | 0.0000 | 0.0000 | 43.0172 | 43.0172 | 0.0000 | 0.0000% |
| 4 | 0.0000 | -16.9228 | 0.0000 | -16.9228 | -16.9135 | 0.0550% |
| 5 | 0.0000 | 0.0000 | 59.9400 | 59.9400 | 0.0000 | 0.0000% |
| 6 | 0.0000 | -65.7450 | 0.0000 | -65.7450 | -65.7423 | 0.0041% |
| 7 | 0.0000 | 0.0000 | 125.6850 | 125.6850 | 0.0000 | 0.0000% |
| 8 | 0.0028 | 0.0000 | 0.0000 | 0.0028 | 0.0000 | 0.0000% |
| **9** | **0.0329** | **0.0000** | **125.6493** | **125.6822** | **0.0000** | **0.0000%** |
| **10** | **0.0246** | **0.0547** | **0.0000** | **0.0793** | **52.0795** | **99.8949%** |
| **11** | **0.0019** | **0.0000** | **-40.3017** | **-40.2998** | **71.0703** | **100.0000%** |
| 12 | 0.0000 | -19.5621 | 0.0000 | -19.5621 | -19.5621 | 0.0000% |
| **13** | **0.0000** | **-20.7396** | **0.0000** | **-20.7396** | **-20.7396** | **0.0000%** |
| **14** | **0.0000** | **0.0000** | **165.8698** | **165.8698** | **0.0000** | **0.0000%** |
| 15 | 0.0834 | 591.6960 | 0.0000 | 591.7794 | 1829.8900 | 67.6649% |
| **16** | **0.0000** | **0.0000** | **-425.9096** | **-425.9096** | **0.0000** | **0.0000%** |
| 17 | 0.0000 | -0.7872 | 0.0000 | -0.7872 | -0.7872 | 0.0001% |
| **18** | **0.0000** | **0.0000** | **-425.1224** | **-425.1224** | **0.0000** | **0.0000%** |
| **19** | **0.0000** | **-1.4399** | **0.0000** | **-1.4399** | **-1.4327** | **0.5018%** |
| **20** | **0.0000** | **0.0000** | **-423.6825** | **-423.6825** | **0.0000** | **0.0000%** |
| **21** | **0.0000** | **0.6322** | **0.0000** | **0.6322** | **6.8210** | **90.7313%** |
| **22** | **0.0000** | **0.0000** | **-424.3147** | **-424.3147** | **116.3010** | **100.0000%** |
| 23 | 0.0086 | -10.1211 | 0.0000 | -10.1125 | -10.1211 | 0.0000% |
| 24 | 0.0000 | 0.0000 | -414.2022 | -414.2022 | 0.0000 | 0.0000% |
| **25** | **0.0000** | **0.1004** | **0.0000** | **0.1004** | **7.3589** | **98.6359%** |
| 26 | 0.0008 | 0.0000 | -414.3034 | -414.3026 | 0.0000 | 0.0000% |
| 27 | 0.0577 | -7.1882 | 0.0000 | -7.1305 | -7.1882 | 0.0004% |
| 28 | 0.0196 | 0.0000 | -407.1925 | -407.1729 | 0.0000 | 0.0000% |
| 29 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000% |
| 30 | 0.0000 | 0.0000 | -407.1925 | -407.1925 | 0.0000 | 0.0000% |
| 31 | 0.4473 | -0.1830 | 0.0000 | 0.2643 | -0.1830 | 0.0000% |
| 32 | 0.0000 | 0.0000 | -407.4567 | -407.4567 | 0.0000 | 0.0000% |
| **33** | **0.0000** | **0.0000** | **0.0000** | **0.0000** | **0.0000** | **0.0000%** |

| SWS | WLA, Mg/yr $CaCO_3$ equivalents | LA, Mg/yr $CaCO_3$ equivalents | Upstream Contribution, Mg/yr $CaCO_3$ equivalents | TMDL, Mg/yr $CaCO_3$ equivalents | Baseline NPS Load, Mg/yr $CaCO_3$ equivalents | Relative NPS Load Reduction |
|---|---|---|---|---|---|---|
| 34 | 0.0000 | 0.0000 | -407.4567 | -407.4567 | 0.0000 | 0.0000% |
| 35 | 0.0183 | -12.0387 | 0.0000 | -12.0204 | -12.0386 | 0.0008% |
| 36 | 0.0000 | 0.0000 | -395.4363 | -395.4363 | 0.0000 | 0.0000% |
| 37 | 0.0000 | 0.0000 | -37.9555 | -37.9555 | 0.0000 | 0.0000% |
| 38 | 0.0000 | -6.4823 | 0.0000 | -6.4823 | -6.4823 | 0.0000% |
| 39 | 0.0000 | -31.4732 | 0.0000 | -31.4732 | -31.4732 | 0.0000% |
| 40 | 0.1625 | 0.0000 | -357.6433 | -357.4808 | 0.0000 | 0.0000% |
| 41 | 0.0000 | -22.7147 | 0.0000 | -22.7147 | -22.7147 | 0.0000% |
| 42 | 0.0473 | 0.0000 | -334.9759 | -334.9286 | 0.0000 | 0.0000% |
| 43 | 0.0000 | -7.8421 | 0.0000 | -7.8421 | -7.8379 | 0.0535% |
| 44 | 0.0000 | 0.0000 | -327.1339 | -327.1339 | 0.0000 | 0.0000% |
| 45 | 0.2113 | -5.0554 | 0.0000 | -4.8442 | -5.0554 | 0.0004% |
| 46 | 0.0065 | 0.0000 | -322.2962 | -322.2897 | 0.0000 | 0.0000% |
| 47 | 0.0000 | -21.5686 | 0.0000 | -21.5686 | -21.5686 | 0.0000% |
| 48 | 0.0010 | 0.0000 | -300.7286 | -300.7276 | 0.0000 | 0.0000% |
| 49 | 0.0000 | -12.0616 | 0.0000 | -12.0616 | -12.0616 | 0.0000% |
| 50 | 0.0000 | 0.0000 | -288.6670 | -288.6670 | 0.0000 | 0.0000% |
| 51 | 0.0000 | 0.0000 | -121.5311 | -121.5311 | 0.0000 | 0.0000% |
| 52 | 0.0962 | 0.0000 | -80.3733 | -80.2771 | 0.0000 | 0.0000% |
| 53 | 0.0000 | -21.3956 | 0.0000 | -21.3956 | -21.3956 | 0.0000% |
| 54 | 0.0000 | -58.9777 | 0.0000 | -58.9777 | -58.9777 | 0.0000% |
| 55 | 0.0000 | -41.2540 | 0.0000 | -41.2540 | -41.2540 | 0.0000% |
| 56 | 0.0000 | 0.0000 | -167.1359 | -167.1359 | 0.0000 | 0.0000% |
| 57 | 0.0000 | -3.2137 | 0.0000 | -3.2137 | -2.9969 | 7.2337% |
| 58 | 0.0000 | 0.0000 | -163.9221 | -163.9221 | 0.0000 | 0.0000% |
| 59 | 0.0000 | -0.4560 | 0.0000 | -0.4560 | -0.4560 | 0.0000% |
| 60 | 0.0000 | 0.0000 | -163.4661 | -163.4661 | 0.0000 | 0.0000% |
| 61 | 0.0000 | -14.9771 | 0.0000 | -14.9771 | -14.9771 | 0.0000% |
| 62 | 0.0000 | -148.4890 | 0.0000 | -148.4890 | -148.4890 | 0.0000% |

Table 5-3. Aluminum TMDL for each of the Paint Creek Sub-Watersheds.

| SWS | WLA, Mg/yr | LA, Mg/yr | Upstream Contribution, Mg/yr | TMDL, Mg/yr |
|---|---|---|---|---|
| **1** | **0.0000** | **0.5657** | **19.9043** | **20.4700** |
| 2 | 0.0000 | 0.0457 | 0.0000 | 0.0457 |
| **3** | **0.0000** | **0.0012** | **19.8574** | **19.8586** |
| 4 | 0.0000 | 0.0106 | 0.0000 | 0.0106 |
| **5** | **0.0000** | **2.2317** | **17.6150** | **19.8467** |
| 6 | 0.0000 | 0.0063 | 0.0000 | 0.0063 |
| **7** | **0.0000** | **0.2631** | **17.3457** | **17.6088** |
| 8 | 0.0163 | 0.0164 | 0.0000 | 0.0327 |
| **9** | **1.0099** | **0.3911** | **15.9120** | **17.3130** |
| **10** | **0.4755** | **0.0079** | **0.0000** | **0.4834** |
| **11** | **0.0598** | **0.0117** | **0.0469** | **0.1184** |
| 12 | 0.0000 | 0.0165 | 0.0000 | 0.0165 |
| **13** | **0.0000** | **0.0304** | **0.0000** | **0.0304** |
| **14** | **0.0000** | **0.0012** | **15.3090** | **15.3102** |
| 15 | 0.4825 | 0.0133 | 0.0000 | 0.4957 |
| **16** | **0.0000** | **0.0027** | **14.8106** | **14.8132** |
| 17 | 0.0000 | 0.0029 | 0.0000 | 0.0029 |
| **18** | **0.0000** | **0.0001** | **14.8075** | **14.8076** |
| **19** | **0.0000** | **0.0044** | **0.0000** | **0.0044** |
| **20** | **0.0000** | **0.1293** | **14.6738** | **14.8031** |
| 21 | 0.0000 | 0.0135 | 0.0000 | 0.0135 |
| **22** | **0.0000** | **0.9552** | **13.7050** | **14.6603** |
| **23** | **0.1100** | **0.0039** | **0.0000** | **0.1140** |
| 24 | 0.0000 | 0.1362 | 13.4549 | 13.5911 |
| 25 | 0.0000 | 0.0112 | 0.0000 | 0.0112 |
| 26 | 0.0254 | 0.0023 | 13.4159 | 13.4436 |
| **27** | **0.3092** | **0.0101** | **0.0000** | **0.3193** |
| 28 | 0.6008 | 0.0042 | 12.4917 | 13.0966 |
| 29 | 0.0000 | 0.0029 | 0.0000 | 0.0029 |
| 30 | 0.0000 | 0.0017 | 12.4870 | 12.4887 |
| 31 | 2.8754 | 0.0091 | 0.0000 | 2.8845 |
| 32 | 0.0000 | 0.0012 | 9.6013 | 9.6025 |
| **33** | **0.0000** | **0.0021** | **0.0000** | **0.0021** |
| 34 | 0.0000 | 0.0041 | 9.5952 | 9.5992 |
| 35 | 0.2678 | 0.0041 | 0.0000 | 0.2719 |

| SWS | WLA, Mg/yr | LA, Mg/yr | Upstream Contribution, Mg/yr | TMDL, Mg/yr |
|---|---|---|---|---|
| 36 | 0.0000 | 0.0001 | 9.3232 | 9.3233 |
| 37 | 0.0000 | 0.0146 | 0.0237 | 0.0383 |
| 38 | 0.0000 | 0.0092 | 0.0000 | 0.0092 |
| 39 | 0.0000 | 0.0145 | 0.0000 | 0.0145 |
| 40 | 4.9906 | 0.0068 | 4.2875 | 9.2849 |
| 41 | 0.0000 | 0.1739 | 0.0000 | 0.1739 |
| 42 | 1.4529 | 0.0031 | 2.6575 | 4.1136 |
| 43 | 0.0000 | 0.0066 | 0.0000 | 0.0066 |
| 44 | 0.0000 | 0.0004 | 2.6505 | 2.6509 |
| 45 | 1.1922 | 0.0055 | 0.0000 | 1.1977 |
| 46 | 0.2002 | 0.2679 | 0.9847 | 1.4529 |
| **47** | **0.0000** | **0.0603** | **0.0000** | **0.0603** |
| 48 | 0.0299 | 0.0098 | 0.8846 | 0.9244 |
| 49 | 0.0000 | 0.0067 | 0.0000 | 0.0067 |
| 50 | 0.0000 | 0.0032 | 0.8747 | 0.8779 |
| 51 | 0.0000 | 0.0017 | 0.8466 | 0.8483 |
| 52 | 0.7899 | 0.0007 | 0.0210 | 0.8116 |
| 53 | 0.0000 | 0.0093 | 0.0000 | 0.0093 |
| 54 | 0.0000 | 0.0117 | 0.0000 | 0.0117 |
| 55 | 0.0000 | 0.0351 | 0.0000 | 0.0351 |
| 56 | 0.0000 | 0.0006 | 0.0258 | 0.0264 |
| 57 | 0.0000 | 0.0040 | 0.0000 | 0.0040 |
| 58 | 0.0000 | 0.0019 | 0.0199 | 0.0218 |
| 59 | 0.0000 | 0.0055 | 0.0000 | 0.0055 |
| 60 | 0.0000 | 0.0023 | 0.0121 | 0.0144 |
| 61 | 0.0000 | 0.0048 | 0.0000 | 0.0048 |
| 62 | 0.0000 | 0.0073 | 0.0000 | 0.0073 |

Table 5-4. Iron TMDL for each of the Paint Creek Sub-Watersheds.

| SWS | WLA, Mg/yr | LA, Mg/yr | Upstream Contribution, Mg/yr | TMDL, Mg/yr |
|---|---|---|---|---|
| 1 | 0.0000 | 0.4210 | 20.8020 | 21.2230 |
| 2 | 0.0000 | 0.0016 | 0.0000 | 0.0016 |
| 3 | 0.0000 | 0.0003 | 20.8001 | 20.8004 |
| 4 | 0.0000 | 0.0022 | 0.0000 | 0.0022 |
| 5 | 0.0000 | 1.4644 | 19.3336 | 20.7979 |
| 6 | 0.0000 | 0.0013 | 0.0000 | 0.0013 |
| 7 | 0.0000 | 0.0370 | 19.2953 | 19.3323 |
| 8 | 0.0637 | 0.0008 | 0.0000 | 0.0646 |
| 9 | 0.7515 | 0.0517 | 18.4274 | 19.2307 |
| **10** | **0.5615** | **0.3620** | **0.0000** | **0.9235** |
| **11** | **0.0445** | **0.0168** | **0.1514** | **0.2127** |
| 12 | 0.0000 | 0.0694 | 0.0000 | 0.0694 |
| **13** | **0.0000** | **0.0820** | **0.0000** | **0.0820** |
| 14 | 0.0000 | 0.0052 | 17.2860 | 17.2912 |
| 15 | 1.1912 | 0.0005 | 0.0000 | 1.1918 |
| 16 | 0.0000 | 0.0112 | 16.0830 | 16.0943 |
| 17 | 0.0000 | 0.0002 | 0.0000 | 0.0002 |
| 18 | 0.0000 | 0.0006 | 16.0822 | 16.0828 |
| **19** | **0.0000** | **0.0084** | **0.0000** | **0.0084** |
| 20 | 0.0000 | 0.0039 | 16.0699 | 16.0738 |
| 21 | 0.0000 | 0.0307 | 0.0000 | 0.0307 |
| 22 | 0.0000 | 0.3409 | 15.6983 | 16.0392 |
| **23** | **0.1956** | **0.0008** | **0.0000** | **0.1964** |
| 24 | 0.0000 | 0.0062 | 15.4957 | 15.5019 |
| 25 | 0.0000 | 0.0082 | 0.0000 | 0.0082 |
| 26 | 0.0189 | 0.0095 | 15.4591 | 15.4875 |
| **27** | **0.7544** | **0.0019** | **0.0000** | **0.7563** |
| 28 | 0.4471 | 0.0176 | 14.2380 | 14.7028 |
| 29 | 0.0000 | 0.0006 | 0.0000 | 0.0006 |
| 30 | 0.0000 | 0.0072 | 14.2303 | 14.2374 |
| 31 | 5.8786 | 0.0360 | 0.0000 | 5.9146 |
| 32 | 0.0000 | 0.0049 | 8.3108 | 8.3157 |
| **33** | **0.0000** | **0.0004** | **0.0000** | **0.0004** |
| 34 | 0.0000 | 0.0170 | 8.2933 | 8.3103 |
| 35 | 0.4180 | 0.0673 | 0.0000 | 0.4853 |

| SWS | WLA, Mg/yr | LA, Mg/yr | Upstream Contribution, Mg/yr | TMDL, Mg/yr |
|---|---|---|---|---|
| 36 | 0.0000 | 0.0004 | 7.8076 | 7.8080 |
| 37 | 0.0000 | 0.0307 | 0.0312 | 0.0619 |
| 38 | 0.0000 | 0.0162 | 0.0000 | 0.0162 |
| 39 | 0.0000 | 0.0150 | 0.0000 | 0.0150 |
| 40 | 1.7409 | 0.0288 | 5.9760 | 7.7457 |
| 41 | 0.0000 | 0.0097 | 0.0000 | 0.0097 |
| 42 | 1.0812 | 0.0013 | 4.8838 | 5.9663 |
| 43 | 0.0000 | 0.0070 | 0.0000 | 0.0070 |
| 44 | 0.0000 | 0.0016 | 4.8752 | 4.8767 |
| 45 | 2.7013 | 0.0023 | 0.0000 | 2.7035 |
| 46 | 0.1490 | 0.0023 | 2.0203 | 2.1717 |
| **47** | **0.0000** | **0.1227** | **0.0000** | **0.1227** |
| 48 | 0.0223 | 0.0020 | 1.8734 | 1.8977 |
| 49 | 0.0000 | 0.0066 | 0.0000 | 0.0066 |
| 50 | 0.0000 | 0.0094 | 1.8574 | 1.8668 |
| 51 | 0.0000 | 0.0003 | 1.7870 | 1.7873 |
| 52 | 1.6622 | 0.0001 | 0.0078 | 1.6701 |
| 53 | 0.0000 | 0.0019 | 0.0000 | 0.0019 |
| 54 | 0.0000 | 0.0059 | 0.0000 | 0.0059 |
| 55 | 0.0000 | 0.1169 | 0.0000 | 0.1169 |
| 56 | 0.0000 | 0.0010 | 0.0691 | 0.0701 |
| 57 | 0.0000 | 0.0080 | 0.0000 | 0.0080 |
| 58 | 0.0000 | 0.0033 | 0.0577 | 0.0610 |
| 59 | 0.0000 | 0.0548 | 0.0000 | 0.0548 |
| 60 | 0.0000 | 0.0005 | 0.0025 | 0.0029 |
| 61 | 0.0000 | 0.0010 | 0.0000 | 0.0010 |
| 62 | 0.0000 | 0.0015 | 0.0000 | 0.0015 |

Table 5-5. Manganese TMDL for each of the Paint Creek Sub-Watersheds.

| SWS | WLA, Mg/yr | LA, Mg/yr | Upstream Contribution, Mg/yr | TMDL, Mg/yr |
|---|---|---|---|---|
| 1 | 0.0000 | 2.631E-01 | 17.8511 | 18.1142 |
| 2 | 0.0000 | 9.223E-06 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 1.191E-06 | 17.8511 | 17.8511 |
| 4 | 0.0000 | 2.471E-04 | 0.0000 | 0.0002 |
| 5 | 0.0000 | 1.312E+00 | 16.5390 | 17.8508 |
| 6 | 0.0000 | 1.863E-02 | 0.0000 | 0.0186 |
| 7 | 0.0000 | 4.109E-03 | 16.5163 | 16.5204 |
| 8 | 0.0398 | 2.748E-03 | 0.0000 | 0.0426 |
| 9 | 0.4697 | 3.806E+00 | 12.1980 | 16.4737 |
| **10** | **0.3509** | **1.901E-02** | **0.0000** | **0.3699** |
| **11** | **0.0278** | **1.059E-02** | **0.1244** | **0.1628** |
| 12 | 0.0000 | 4.534E-02 | 0.0000 | 0.0453 |
| **13** | **0.0000** | **7.901E-02** | **0.0000** | **0.0790** |
| 14 | 0.0000 | 1.186E-06 | 11.6653 | 11.6653 |
| 15 | 0.6373 | 6.466E-04 | 0.0000 | 0.6380 |
| 16 | 0.0000 | 2.555E-06 | 11.0273 | 11.0273 |
| 17 | 0.0000 | 3.782E-06 | 0.0000 | 0.0000 |
| 18 | 0.0000 | 1.358E-07 | 11.0273 | 11.0273 |
| **19** | **0.0000** | **4.441E-03** | **0.0000** | **0.0044** |
| 20 | 0.0000 | 6.027E-02 | 10.9626 | 11.0229 |
| 21 | 0.0000 | 2.229E-02 | 0.0000 | 0.0223 |
| 22 | 0.0000 | 4.443E-01 | 10.4960 | 10.9403 |
| **23** | **0.1222** | **1.030E-05** | **0.0000** | **0.1222** |
| 24 | 0.0000 | 6.355E-02 | 10.3102 | 10.3738 |
| 25 | 0.0000 | 2.009E-02 | 0.0000 | 0.0201 |
| 26 | 0.0118 | 2.168E-06 | 10.2783 | 10.2901 |
| **27** | **0.4328** | **2.644E-04** | **0.0000** | **0.4331** |
| 28 | 0.2794 | 4.012E-06 | 9.5658 | 9.8452 |
| 29 | 0.0000 | 1.907E-05 | 0.0000 | 0.0000 |
| 30 | 0.0000 | 1.629E-06 | 9.5658 | 9.5658 |
| 31 | 3.1949 | 9.147E-03 | 0.0000 | 3.2040 |
| 32 | 0.0000 | 1.118E-06 | 6.3617 | 6.3617 |
| **33** | **0.0000** | **4.854E-06** | **0.0000** | **0.0000** |
| 34 | 0.0000 | 3.876E-06 | 6.3617 | 6.3617 |
| 35 | 0.2586 | 2.683E-02 | 0.0000 | 0.2855 |

| SWS | WLA, Mg/yr | LA, Mg/yr | Upstream Contribution, Mg/yr | TMDL, Mg/yr |
|---|---|---|---|---|
| 36 | 0.0000 | 9.040E-08 | 6.0762 | 6.0762 |
| 37 | 0.0000 | 5.479E-04 | 0.0748 | 0.0753 |
| 38 | 0.0000 | 6.082E-02 | 0.0000 | 0.0608 |
| 39 | 0.0000 | 1.395E-02 | 0.0000 | 0.0140 |
| 40 | 2.3212 | 6.547E-06 | 3.6797 | 6.0009 |
| 41 | 0.0000 | 5.354E-02 | 0.0000 | 0.0535 |
| 42 | 0.6758 | 3.000E-06 | 2.9504 | 3.6262 |
| 43 | 0.0000 | 4.350E-03 | 0.0000 | 0.0043 |
| 44 | 0.0000 | 3.569E-07 | 2.9461 | 2.9461 |
| 45 | 1.5091 | 2.353E-05 | 0.0000 | 1.5091 |
| 46 | 0.0931 | 1.249E-01 | 1.2189 | 1.4369 |
| **47** | **0.0000** | **1.850E-03** | **0.0000** | **0.0018** |
| 48 | 0.0139 | 9.422E-06 | 1.2031 | 1.2171 |
| 49 | 0.0000 | 6.575E-03 | 0.0000 | 0.0066 |
| 50 | 0.0000 | 3.085E-06 | 1.1966 | 1.1966 |
| 51 | 0.0000 | 1.621E-06 | 1.1038 | 1.1038 |
| 52 | 1.0509 | 6.523E-07 | 0.0060 | 1.0568 |
| 53 | 0.0000 | 9.497E-05 | 0.0000 | 0.0001 |
| 54 | 0.0000 | 5.870E-03 | 0.0000 | 0.0059 |
| 55 | 0.0000 | 4.693E-02 | 0.0000 | 0.0469 |
| 56 | 0.0000 | 5.367E-07 | 0.0928 | 0.0928 |
| 57 | 0.0000 | 2.009E-02 | 0.0000 | 0.0201 |
| 58 | 0.0000 | 1.772E-06 | 0.0727 | 0.0727 |
| 59 | 0.0000 | 2.745E-02 | 0.0000 | 0.0275 |
| 60 | 0.0000 | 2.229E-06 | 0.0452 | 0.0452 |
| 61 | 0.0000 | 4.522E-02 | 0.0000 | 0.0452 |
| 62 | 0.0000 | 6.988E-06 | 0.0000 | 0.0000 |

Table 5-6. NPDES Effluent Concentration Ranges for Wasteload Allocations.

| Water Quality Parameter | Wasteload Allocation Range |
|---|---|
| PH | ≥ 6.0, ≤ 9.0 S.U. |
| Aluminum | 0.75 - 4.3 mg/L |
| Iron | 0.5[1] or 1.5[2] - 3.2 mg/L |
| Manganese | 1.0 - 2.0 mg/L |

[1]Water quality standard for total iron concentration in trout waters.
[2]Water quality standard for total iron concentration in warm waters.

The wasteload allocations must be converted to permit average monthly limits and maximum daily limits according to the technical support document, which considers the type of water quality criteria (acute, chronic, human health, maximum allowable, four-day average, etc.), effluent variability, and monitoring requirements. For an iron wasteload allocation of 3.2 mg/l, the average monthly value is 3.0 mg/l, the maximum daily limit is 5.2 mg/l, the assumed effluent variability is 0.6, and two samples per month are required. A manganese wasteload allocation equal to 2.0 mg/L translates into an average monthly limit of 2.0 mg/L and a maximum daily limit of 3.5 mg/L. Presently aluminum is not limited in permits but will be required in any new or reissued permits. An aluminum wasteload allocation equal to 4.3 mg/L translates into an average monthly limit of 2.5 mg/L and a maximum daily limit of 4.3 mg/L.

### 5.4.2 Load Allocations

Load allocations were made for the following dominant source categories:

1. Abandoned mine lands.
2. Revoked mining permits.

The load allocations for acidity, aluminum, iron and manganese for all of the stream segments in the Paint Creek watershed are listed in both Appendix F and Tables 5-2, 5-3, 5-4, and 5-5. The bold rows in these tables correspond to stream segments placed on the 303(d) list for the appropriate contaminant. These load allocations are presented as annual loads, in terms of metric tons (Mg) per year. They are presented on an annual basis (as an annual load), because they were developed to meet TMDL endpoints under a range of conditions observed throughout the year. The water quality data collected from some of the Paint Creek sub-watersheds indicate the presence of abandoned mine land that is not found on any available GIS coverage of abandoned mine lands (AML). While the precise locations of these AML sites are not known, this load allocation assumes that stream water quality condition is the best indicator of the presence of AML.

### 5.4.3 Seasonal Variations

A TMDL must consider seasonal variation in the derivation of the allocation. For the Paint Creek watershed pH and metals TMDLs, seasonal variation was considered in the formulation of the modeling analysis. By using continuous simulation (modeling over a period of several years), seasonal hydrologic and source loading variability was inherently considered. The simulated pH and metals concentrations were calculated on a daily time step by the model were compared to TMDL endpoints. An allocation, which meets these endpoints throughout the year, was developed.

### 5.4.4 Future Growth

This TMDL does not include specific future growth allocations to each subwatershed. Because of the general allocation philosophy used in this TMDL, such allocations would be made at the expense of active mining point sources in the watershed. However, the absence of specific future growth allocations does not prohibit new mining in the watershed. Future growth could occur in the watershed under the following scenarios:

1. A new facility could be permitted anywhere in the watershed, provided that effluent limitations are based upon the achievement of water quality standards end-of-pipe for the pollutants of concern in the TMDL.

2. Remining could occur without a specific allocation to the new permittee, if the requirements of existing State remining regulations are achieved. Remining activities are viewed as a partial non-point source load reduction from Abandoned Mine Lands.

3. Reclamation and release of existing permits could provide an opportunity for future growth if permit release is conditioned upon achieving discharge quality better than the wasteload allocation prescribed by the TMDL.

The TMDL may be refined in the future through remodeling. Such refinement may incorporate new information and/or to the redistribute pollutant loads. Trading may provide an additional opportunity for future growth, contingent upon the State's development of a statewide or watershed-based trading program.

### 5.4.5 Water Quality Trading

This TMDL neither prohibits nor authorizes trading in the Paint Creek watershed. Both the WVDEP and EPA generally endorse the concept of trading, and recognize that it may become an effective tool for TMDL implementation.

However, significant regulatory framework development is necessary before large-scale trading in West Virginia may be realized. EPA will cooperate with the WVDEP in their development of a statewide or watershed-based trading program. Further, EPA supports program development assisted by a consensus-based stakeholder process.

Prior to the development of a formal trading program, it is conceivable that the regulation of specific point source to point source trades may be feasible under the framework of the NPDES program. EPA commits to cooperate with the WVDEP to facilitate such trades if trading opportunities arise and are proven environmentally beneficial.

## 6.0 Reasonable Assurance

Two primary programs are in effect which provide reasonable assurance for maintenance and improvement of water quality in the watershed. WVDEP's efforts to reclaim abandoned mine lands, coupled with its duties and responsibilities for issuance of NPDES permits, will be the focal points in water quality improvement.

Additional opportunities for water quality improvement are both ongoing and anticipated. Historically, a great deal of research into mine drainage has been conducted by scientists at West Virginia University, the West Virginia Division of Natural Resources, the United States Office of Surface Mining, the National Mine Land Reclamation Center, the National Environmental Training Laboratory and many other agencies and individuals. Funding from EPA's 319 grant program has been used extensively to remedy mine drainage impacts. This myriad of activity is expected to continue and result in water quality improvement.

## 6.1 Reclamation

Two distinct units of WVDEP reclaim land and water resources impacted by abandoned mines. The Office of Abandoned Mine Lands and Reclamation remedies eligible sites under Title IV of the Surface Mining Control and Reclamation Act of 1977. The Office of Mining and Reclamation's Special Reclamation Program remedies sites where operating permits and bonds have been revoked. Funding of the Office of Abandoned Mine Lands and Reclamation is derived from a federal tax on coal producers. The Special Reclamation Program is funded by the Special Reclamation Fund, which has primary sources of income from civil penalties, forfeited bonds, and a three-cent per ton fee on all coal produced.

A description of the operating procedures and accomplishments of each program follows.

### 6.1.1 Office of Abandoned Mine Lands and Reclamation

Title IV of the Surface Mining Control and Reclamation Act (Public Law 95-87) is designed to help reclaim and restore coal mine areas abandoned prior to August 3, 1977, throughout the country. The AML Program supplements existing state programs and allows the State of West Virginia to correct many abandoned mine related problems that would otherwise not be addressed. The major purpose of the AML Program is to reclaim and restore abandoned mine areas to protect the health, safety, and general welfare of the public and the environment. The AML Program corrects abandoned mine-related problems in accordance with the prioritization process specified in Public Law 95-87, Section 403 (a), 1-3. The priorities of the AML Program are as follows:

1. Protection of public health, safety, general welfare, and property from extreme danger of adverse effects related to coal mining practices.
2. Protection of public health, safety, and general welfare from adverse effects related to coal mining practices.
3. Restoration of the environment, including the land and water resources, that were degraded by adverse effects related to coal mining practices. This involves the conservation and development of soil, water (not channelization), woodland, fish and wildlife, recreational resources, and agricultural productivity.

Priority 1 and 2 problem areas include unsafe refuse piles, treacherous highwalls, pollution of domestic water supplies from mine drainage, mine fires, subsidence and other abandoned mine-related problems. The AML Program is now also focused on Priority 3 problem areas and on treating and abating water quality problems associated with abandoned mine lands but is not required by law or any statutory authority to do so. By recognizing the need to protect, and in many cases, improve the quality of the state's water resources from the impacts of mine drainage pollution from abandoned coal mines, coordinated efforts are now being employed to deal with this non-point source pollution problem.

Although OAML&R has been actively involved in the successful remediation of mine drainage pollution, inadequate funding and the lack of cost-effective mine drainage pollution treatment and abatement technologies have limited water quality improvement efforts. In 1990, the Surface Mining Control and Reclamation Act was amended to include a provision allowing states and tribes to establish an Acid Mine Drainage Treatment and Abatement Program and Fund. States and tribes may set-aside up to 10% of their annual grant to begin to address abandoned polluted coal mine drainage problems. Money from the Acid Mine Drainage Treatment and Abatement Fund can be utilized to clean-up mine drainage pollution at sites where mining ceased prior to August 3, 1977, and where no continuing reclamation responsibility can be determined. In order to qualify and be eligible, qualified hydrologic units or watersheds must be identified and water quality must adversely impact biological resources. A plan must be prepared and presented to the Natural Resources Conservation Service for review and the Office of Surface Mining for approval.  Plans that include the most cost-effective treatment and abatement alternatives, the greatest down-stream benefits to the ecosystem, and diverse cooperators and stakeholders, will be the highest priority for approval.

AML&R has created an Acid Mine Drainage Abatement Policy to guide efforts in treating and abating mine drainage pollution.  The Policy acts to guide the expenditure of funds in order to achieve the maximum amount of mine drainage pollution treatment within the boundaries imposed by budgetary and statutory constraints.  The goal is to utilize existing technologies and practical economic considerations to maximize the amount of treatment for dollars expended.  The policy includes a holistic watershed characterization and remediation procedure known as the Holistic Watershed Approach Protocol, which was developed and implemented by the Stream Restoration Group of AML&R.  The Protocol involves diverse stakeholders in the establishment of various sampling networks and subsequent water quality data generation that focus remediation efforts.  The Protocol is first used to subdivide the watershed into focus areas.  More specific data is then generated to allow identification of the most feasible pollution sources to address and the best available pollution abatement technology to apply.  The Protocol also includes the establishment of post-construction sampling networks to assess the impacts of remediation efforts.  The Protocol is iteratively implemented until all focus areas have been addressed and all feasible pollution abatement technologies have been applied.  A detailed description of the Protocol was presented by Vukovich and Adolfson (2001), which was modified to prepare Appendix G of this report.

### 6.1.2 Special Reclamation Group

When notice of permit revocation is received from the Director, a liability estimate is completed within 60 days of the revocation.  The liability estimate notes any special health and safety characteristics of the site and calculates the cost to complete reclamation according to the permit reclamation plan.  At sites where acid mine drainage is present, the permit is flagged for water quality characterization and a priority index assigned.

The reclamation plan at all sites includes the application of the best professional judgment to address the site specific problems including acid mine drainage. Any change or modification to the permit reclamation plan is done by or under the supervision of a Registered Professional Engineer.  All construction requires application of best management practices to insure quality work and protect the environment.

Prioritization of bond forfeiture sites is consistent with the criteria used in the Abandoned Mine Land and Reclamation (AML&R) program.  The criteria, listed below in order of priority, have been used successfully for many years on abandoned mine areas with similar characteristics to bond forfeiture sites.

1. The highest priority sites are those that entail protection of public health, safety, general welfare, and property from extreme danger. There are relatively few of these types of bond forfeiture sites; however, they are unquestionably first order priorities.

2. Second order priority sites are those where public health, safety, welfare, and property values are judged to be threatened. Examples include sites with a high potential for landslides or flooding or the presence of dangerous highwalls, derelict buildings or other structures.

3. Third order priorities comprise the bulk of bond forfeiture sites. Therefore, this ranking level is sub-divided into smaller groupings.

    3.1. The first sub-group is sites that are causing or have a high potential for causing off-site environmental damage to the land and water resources. Such off-site damage would most likely be from heavy erosion, or high loadings of acid mine drainage.

    3.2. The second sub-group would include sites that are of a lower priority, but are in close geographic proximity to first or second priority sites. It is more efficient and cost effective to "cluster" projects where possible.

    3.3. The third sub-group includes sites near high-use public recreation areas and major thoroughfares.

    3.4. The fourth sub-group includes sites that are nearly fully reclaimed by the operator and only require monitoring of vegetative growth or other parameters. Sites, which have a real potential for re-permitting by another operator or reclamation by a third party, will also be placed in this sub-group.

Reclamation construction contracts occur by submittal of a detailed Project Requisition to the State Purchasing Division. All state purchasing policies and procedures are applicable and the contract is awarded to the lowest qualified bidder. Special Reclamation personnel perform inspection and contract management activities through the life of the contract. When all reclamation work is satisfactorily completed, a one-year contract warranty period begins to insure adequate vegetative growth and drainage system operation. Upon completion of the contract warranty period and recommendation of the Regional Supervisor, the permit status is classified as “completed.” A completed status removes the liability of the forfeited site and terminates WVDEP jurisdiction and responsibility as a Phase III bond release.

At the sites with significant and high priority AMD, treatment operations are conducted to the extent of available funding, pursuant to the authority granted in 22-3-11 (g) of the West Virginia Surface Coal Mining and Reclamation Act. That regulation limits the annual expenditure of funds for designing, constructing and maintaining water treatment systems to 25% of the annual amount of the fees collected.

## 6.2 Permitting

NPDES permits in the watershed will be issued, reissued or modified by the Office of Water Resources in close cooperation with the Office of Mining and Reclamation. Both offices have adjusted permitting schedules to accommodate the State's Watershed Management Framework, thus implementation of TMDL requirements at existing facilities will generally occur at the time of scheduled permit re-issuance. Permits for existing facilities in the Paint Creek watershed are scheduled to be reissued in 2001. WVDEP may provide short-term administrative extensions to expiring permits to ensure adequate time is available to properly implement the wasteload allocations of this TMDL.

# 7.0 Public Participation

EPA policy is that there must be full and meaningful public participation in the TMDL development process. Each state must, therefore, provide for public participation consistent with its own continuing planning process and public participation requirements. As a result, it is the intent of the WVDEP to solicit public input by providing opportunities for public comment and review of the draft TMDLs. The public meetings pertaining to the Paint Creek watershed occurred as follows:

| | |
|---|---|
| May 10, 2000 | Public meeting presenting an introduction to the TMDL process, together with the requirements of the consent decree. |
| February 27, 2001 | Public meeting presented by WVDEP, EPA and WVU. |
| July 25 – September 7, 2001 | 45-day public comment period, published in the Charleston Gazette and Fayette Tribune |
| August 27, 2001 | Public hearing held by WVDEP and EPA |

## 8.0 References


Fletcher, J.J., and M.P. Strager. 2000. Extending the Capabilities of the Watershed Characterization and Modeling System. Final Technical Report. National Resources Analysis Center, West Virginia University, Morgantown, WV.

Geidel, G., and F.T. Caruccio. 2000. Geochemical factors affecting coal mining drainage quality. p. 105-130. *In* R.I. Barnhisel et al. (ed) Reclamation of Drastically Disturbed Lands. Agron. Monpgr. 41. ASA, CSSA, and SSSA, Madison, WI.

Leathen, W.W., S.A. Braley, and L.D. McIntyre. 1953. The role of bacteria in the formation of acid from certain sulfuritic constituents associated with bituminous coal. Appl. Microbiol. 1:61-68.

Skousen, J.G., A. Sexstone, and P.F. Ziemkiewicz. 2000. Acid mine drainage control and treatment. p. 131-168. *In* R.I. Barnhisel et al. (ed) Reclamation of Drastically Disturbed Lands. Agron. Monpgr. 41. ASA, CSSA, and SSSA, Madison, WI.

Stumm, W., and J.J. Morgan. 1970. Aquatic chemistry. John Wiley & Sons, Inc., New York, NY.

Surface Mine Control and Reclamation Act. 1977. Public Law 95-87.

USEPA. 1991. Technical Support Document for Water Quality-based Toxics Control. EPA/505/2-90-001. United States Environmental Protection Agency; Office of Water, Washington, D.C.

Vukovich S.M. and G.E. Adolfson. 2001. Holistic Watershed Approach Protocol for Integrated Watershed Characterizations. Integrated Decision Making for Watershed Management Symposium. Washington, D.C.

Waksman, S.A. 1922. Microorganisms concerned in the oxidation of sulfur in the soil IV. A solid medium for the isolation and cultivation of *Thiobacillus thiooxidans*. J. Bact. 7:605-608.

Watts, K.C., Jr., M.E. Hinkle and W.R. Griffitts. 1994. Isopleth Maps of Titanium, Aluminum, and Associated Elements in Stream Segments of West Virginia. Miscellaneous Investigations Series. United States Department of the Interior, United States Geological Survey, Washington, D.C.

## Appendix A    Mining NPDES Permits in Paint Creek Watershed.

**Table A1**. Paint Creek NPDES Permits and Associated Article 3 & 4 Permits.

| NPDES Permit | Associated Article 3 & 4 Permit # and Status | | | | | |
|---|---|---|---|---|---|---|
| | Not Started | Active | Phase 1 | Phase 2 | Phase 3 | Revoked |
| WV1001370 | | O304887 | | | | |
| WV0096679 | | | O017083 | | | |
| WV1002066 | | | | S301089 | | |
| WV1012631 | | | | | U017700 | |
| WV0097071 | | | | | | U022583 |
| WV1012487 | | S300295 | | | | |
| WV1012487 | | S303991 | | | | |
| WV1012487 | | | | | S302389 | |
| WV1012592 | | S304191 | | | | |
| WV1014951 | | O300595 | | | | |
| WV1014951 | | Q301696 | | | | |
| WV1014951 | | S302794 | | | | |
| WV1015214 | | S301496 | | | | |
| WV0057011 | | O602289 | | | | |
| WV0057011 | | H066700 | | | | |
| WV0092142 | | Q000182 | | | | |
| WV0092142 | | Q013380 | | | | |
| WV0092142 | | Q020078 | | | | |
| WV0092142 | | Q302286 | | | | |
| WV0092142 | | | | | | Q009873 |
| WV1009311 | | S300795 | | | | |
| WV1009311 | | S304387 | | | | |
| WV1009311 | | S602089 | | | | |
| WV1002074 | | O301489 | | | | |
| WV1002074 | | | | S300391 | | |
| WV1002074 | | | | S301589 | | |
| WV1002074 | | | | S302186 | | |
| WV0028452 | | O301993 | | | | |
| WV0028452 | | O301198 | | | | |
| WV0028452 | | | | | P069400 | |
| WV0028452 | | S007480 | | | | |
| WV0028452 | | U042800 | | | | |
| WV0028452 | | | U300395 | | | |
| WV0028452 | | U300496 | | | | |
| WV0028452 | | | U300591 | | | |
| WV0028452 | | | | | U300596 | |
| WV0028452 | U300597 | | | | | |
| WV0028452 | | | | | U302290 | |
| WV0028452 | | | | U302591 | | |
| WV1002368 | | U301996 | | | | |
| WV1002368 | | U302990 | | | | |
| WV1002368 | | | | | U304489 | |
| WV1019317 | | O0301489 | | | | |
| WV1015257 | | O601186 | | | | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV0057011 | 001 | 38 05 32.0 N | 81 20 59.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 002 | 38 05 31.0 N | 81 20 57.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 003 | 38 05 21.0 N | 81 21 22.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 004 | 38 05 40.0 N | 81 21 03.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 005 | 38 05 47.0 N | 81 20 56.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 006 | 38 05 40.0 N | 81 21 15.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 007 | 38 05 27.0 N | 81 21 41.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 008 | 38 05 26.0 N | 81 21 37.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 009 | 38 05 25.0 N | 81 21 19.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 010 | 38 05 14.0 N | 81 21 06.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 011 | 38 05 11.0 N | 81 20 51.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 012 | 38 05 31.0 N | 81 21 47.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 013 | 38 05 43.0 N | 81 21 44.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 014 | 38 05 21.0 N | 81 21 22.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 015 | 38 05 17.0 N | 81 21 16.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 016 | 38 05 19.0 N | 81 21 22.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 017 | 38 05 34.0 N | 81 21 12.0 W | Reissued | Technology Based | Inactive | |
| WV0057011 | 018 | 38 04 35.0 N | 81 21 09.0 W | Reissued | Technology Based | Active | |
| WV0057011 | 019 | 38 03 16.0 N | 81 20 43.0 W | Reissued | Technology Based | Inactive | |
| WV0092142 | 001 | 37 51 26.0 N | 81 15 07.0 W | Open | Technology Based | Active | Sandstone Quarry |
| WV0092142 | 002 | 37 51 25.0 N | 81 14 55.0 W | Open | Technology Based | Active | Sandstone Quarry |
| WV0092142 | 003 | 37 51 17.0 N | 81 15 01.0 W | Open | Technology Based | Inactive | Sandstone Quarry |
| WV0092142 | 004 | 37 51 24.0 N | 81 15 01.0 W | Open | Technology Based | Inactive | Sandstone Quarry |
| WV0096679 | 001 | 37 59 57.0 N | 81 20 34.0 W | Open | Technology Based | Inactive | |
| WV1001370 | 001 | 37 50 22.0 N | 81 15 47.0 W | Open | Technology Based | Inactive | |
| WV1002066 | 001 | 37 55 58.0 N | 81 17 10.0 W | Open | Technology Based | Active | |
| WV1002066 | 002 | 37 56 01.0 N | 81 17 01.0 W | Open | Technology Based | Active | |
| WV1002066 | 003 | 37 56 01.0 N | 81 17 29.0 W | Open | Technology Based | Active | |
| WV1002066 | 004 | 37 56 18.0 N | 81 17 14.0 W | Open | Technology Based | Active | |
| WV1002066 | 005 | 37 56 22.0 N | 81 17 11.0 W | Open | Technology Based | Active | |
| WV1002066 | 006 | 37 56 07.0 N | 81 17 22.0 W | Open | Technology Based | Active | |
| WV1002368 | 001 | 38 00 07.0 N | 81 19 11.0 W | Open | Technology Based | Active | |
| WV1002368 | 002 | 37 59 42.0 N | 81 19 09.0 W | Open | Technology Based | Active | |
| WV1002368 | 003 | 37 59 40.0 N | 81 19 11.0 W | Open | Technology Based | Active | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV1002368 | 004 | 38 00 18.0 N | 81 19 08.0 W | Open | Technology Based | Active | |
| WV1002368 | 005 | 38 00 12.0 N | 81 19 06.0 W | Open | Technology Based | Active | |
| WV1009311 | 001 | 38 02 47.0 N | 81 20 25.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 002 | 38 03 15.0 N | 81 20 30.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 003 | 38 03 35.0 N | 81 20 12.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 004 | 38 03 16.0 N | 81 21 56.0 W | Open | Technology Based | Active | |
| WV1009311 | 005 | 38 03 37.0 N | 81 22 09.0 W | Open | Technology Based | Active | |
| WV1009311 | 006 | 38 02 41.0 N | 81 21 45.0 W | Open | Technology Based | Active | |
| WV1009311 | 007 | 38 04 05.0 N | 81 20 24.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 008 | 38 04 20.0 N | 81 22 24.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 009 | 38 04 17.0 N | 81 22 20.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 010 | 38 04 10.0 N | 81 22 13.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 011 | 38 04 02.0 N | 81 22 01.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 012 | 38 03 56.0 N | 81 21 48.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 013 | 38 03 53.0 N | 81 21 35.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 014 | 38 03 54.0 N | 81 21 27.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 015 | 38 03 57.0 N | 81 21 13.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 016 | 38 04 08.0 N | 81 20 37.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 017 | 38 04 36.0 N | 81 21 59.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 018 | 38 04 23.0 N | 81 22 15.0 W | Open | Technology Based | Inactive | |
| WV1009311 | 055 | 38 04 23.0 N | 81 22 15.0 W | Open | Technology Based | Inactive | Estimated Location |
| WV1012487 | 003 | 37 57 40.0 N | 81 16 20.0 W | Open | Technology Based | Active | |
| WV1012487 | 004 | 37 57 37.0 N | 81 16 25.0 W | Open | Technology Based | Active | |
| WV1012487 | 005 | 37 57 30.0 N | 81 16 11.0 W | Open | Technology Based | Active | |
| WV1012487 | 006 | 37 57 12.0 N | 81 16 16.0 W | Open | Technology Based | Active | |
| WV1012487 | 007 | 37 57 17.0 N | 81 15 44.0 W | Open | Technology Based | Active | |
| WV1012487 | 008 | 37 57 17.0 N | 81 15 42.0 W | Open | Technology Based | Active | |
| WV1012487 | 009 | 37 57 13.0 N | 81 15 43.0 W | Open | Technology Based | Active | |
| WV1012487 | 010 | 37 57 07.0 N | 81 15 47.0 W | Open | Technology Based | Active | |
| WV1012487 | 011 | 37 57 06.0 N | 81 15 38.0 W | Open | Technology Based | Active | |
| WV1012487 | 012 | 37 57 04.0 N | 81 15 39.0 W | Open | Technology Based | Active | |
| WV1012487 | 013 | 37 56 54.0 N | 81 15 31.0 W | Open | Technology Based | Active | |
| WV1012487 | 014 | 37 56 59.0 N | 81 15 37.0 W | Open | Technology Based | Active | |
| WV1012487 | 015 | 37 56 53.0 N | 81 15 36.0 W | Open | Technology Based | Active | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV1012487 | 016 | 37 56 49.0 N | 81 15 36.0 W | Open | Technology Based | Active | |
| WV1012487 | 017 | 37 56 50.0 N | 81 15 40.0 W | Open | Technology Based | Active | |
| WV1012487 | 018 | 37 56 46.0 N | 81 15 56.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 019 | 37 56 42.0 N | 81 16 03.0 W | Open | Technology Based | Active | |
| WV1012487 | 020 | 37 56 39.0 N | 81 15 56.0 W | Open | Technology Based | Active | |
| WV1012487 | 021 | 37 56 34.0 N | 81 15 34.0 W | Open | Technology Based | Active | |
| WV1012487 | 022 | 37 56 36.0 N | 81 15 58.0 W | Open | Technology Based | Active | |
| WV1012487 | 023 | 37 56 30.0 N | 81 15 58.0 W | Open | Technology Based | Active | |
| WV1012487 | 024 | 37 56 18.0 N | 81 15 56.0 W | Open | Technology Based | Active | |
| WV1012487 | 025 | 37 56 21.0 N | 81 16 11.0 W | Open | Technology Based | Active | |
| WV1012487 | 026 | 37 56 18.0 N | 81 16 05.0 W | Open | Technology Based | Active | |
| WV1012487 | 027 | 37 56 11.0 N | 81 16 40.0 W | Open | Technology Based | Active | |
| WV1012487 | 028 | 37 56 11.0 N | 81 16 35.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 029 | 37 56 12.0 N | 81 16 27.0 W | Open | Technology Based | Active | |
| WV1012487 | 030 | 37 56 17.0 N | 81 16 22.0 W | Open | Technology Based | Active | |
| WV1012487 | 031 | 37 56 06.0 N | 81 16 41.0 W | Open | Technology Based | Active | |
| WV1012487 | 032 | 37 57 19.0 N | 81 15 54.0 W | Open | Technology Based | Active | |
| WV1012487 | 033 | 37 57 15.0 N | 81 15 52.0 W | Open | Technology Based | Active | |
| WV1012487 | 034 | 37 57 16.0 N | 81 15 49.0 W | Open | Technology Based | Active | |
| WV1012487 | 035 | 37 57 12.0 N | 81 16 15.0 W | Open | Technology Based | Active | |
| WV1012487 | 036 | 37 57 21.0 N | 81 16 18.0 W | Open | Technology Based | Active | |
| WV1012487 | 037 | 37 57 15.0 N | 81 16 18.0 W | Open | Technology Based | Active | |
| WV1012487 | 038 | 37 57 08.0 N | 81 16 09.0 W | Open | Technology Based | Active | |
| WV1012487 | 039 | 37 57 14.0 N | 81 16 10.0 W | Open | Technology Based | Active | |
| WV1012487 | 040 | 37 57 16.0 N | 81 16 06.0 W | Open | Technology Based | Active | |
| WV1012487 | 041 | 37 57 16.0 N | 81 16 02.0 W | Open | Technology Based | Active | |
| WV1012487 | 042 | 37 57 11.0 N | 81 16 00.0 W | Open | Technology Based | Active | |
| WV1012487 | 043 | 37 55 54.0 N | 81 17 23.0 W | Open | Technology Based | Active | |
| WV1012487 | 044 | 37 56 11.0 N | 81 16 51.0 W | Open | Technology Based | Active | |
| WV1012487 | 045 | 37 56 15.0 N | 81 16 56.0 W | Open | Technology Based | Active | |
| WV1012487 | 046 | 37 56 07.0 N | 81 16 56.0 W | Open | Technology Based | Active | |
| WV1012487 | 047 | 37 56 03.0 N | 81 16 55.0 W | Open | Technology Based | Active | |
| WV1012487 | 048 | 37 56 24.0 N | 81 16 43.0 W | Open | Technology Based | Active | |
| WV1012487 | 049 | 37 56 26.0 N | 81 16 42.0 W | Open | Technology Based | Active | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV1012487 | 050 | 37 56 26.0 N | 81 16 36.0 W | Open | Technology Based | Active | |
| WV1012487 | 051 | 37 56 31.0 N | 81 16 26.0 W | Open | Technology Based | Active | |
| WV1012487 | 052 | 37 56 36.0 N | 81 16 26.0 W | Open | Technology Based | Active | |
| WV1012487 | 053 | 37 56 35.0 N | 81 16 22.0 W | Open | Technology Based | Active | |
| WV1012487 | 054 | 37 56 31.0 N | 81 16 19.0 W | Open | Technology Based | Active | |
| WV1012487 | 055 | 37 56 28.0 N | 81 16 14.0 W | Open | Technology Based | Active | |
| WV1012487 | 056 | 37 56 37.0 N | 81 16 02.0 W | Open | Technology Based | Active | |
| WV1012487 | 057 | 37 56 40.0 N | 81 16 04.0 W | Open | Technology Based | Active | |
| WV1012487 | 058 | 37 56 42.0 N | 81 16 11.0 W | Open | Technology Based | Active | |
| WV1012487 | 059 | 37 56 47.0 N | 81 16 03.0 W | Open | Technology Based | Active | |
| WV1012487 | 060 | 37 56 50.0 N | 81 15 59.0 W | Open | Technology Based | Active | |
| WV1012487 | 061 | 37 56 52.0 N | 81 15 53.0 W | Open | Technology Based | Active | |
| WV1012487 | 062 | 37 56 54.0 N | 81 15 48.0 W | Open | Technology Based | Active | |
| WV1012487 | 063 | 37 57 03.0 N | 81 15 51.0 W | Open | Technology Based | Active | |
| WV1012487 | 064 | 37 57 07.0 N | 81 15 52.0 W | Open | Technology Based | Active | |
| WV1012487 | 065 | 37 57 09.0 N | 81 15 52.0 W | Open | Technology Based | Active | |
| WV1012487 | 066 | 37 57 06.0 N | 81 15 56.0 W | Open | Technology Based | Active | |
| WV1012487 | 067 | 37 57 03.0 N | 81 16 00.0 W | Open | Technology Based | Active | |
| WV1012487 | 068 | 37 57 07.0 N | 81 16 02.0 W | Open | Technology Based | Active | |
| WV1012487 | 069 | 37 57 06.0 N | 81 16 03.0 W | Open | Technology Based | Active | |
| WV1012487 | 070 | 37 57 01.0 N | 81 16 04.0 W | Open | Technology Based | Active | |
| WV1012487 | 071 | 37 57 03.0 N | 81 16 08.0 W | Open | Technology Based | Active | |
| WV1012487 | 072 | 37 57 02.0 N | 81 16 09.0 W | Open | Technology Based | Active | |
| WV1012487 | 073 | 37 56 56.0 N | 81 16 10.0 W | Open | Technology Based | Active | |
| WV1012487 | 074 | 37 57 02.0 N | 81 16 21.0 W | Open | Technology Based | Active | |
| WV1012487 | 075 | 37 57 02.0 N | 81 16 31.0 W | Open | Technology Based | Active | |
| WV1012487 | 076 | 37 57 06.0 N | 81 16 36.0 W | Open | Technology Based | Active | |
| WV1012487 | 077 | 37 57 10.0 N | 81 16 37.0 W | Open | Technology Based | Active | |
| WV1012487 | 078 | 37 57 12.0 N | 81 16 40.0 W | Open | Technology Based | Active | |
| WV1012487 | 079 | 37 57 14.0 N | 81 16 34.0 W | Open | Technology Based | Active | |
| WV1012487 | 080 | 37 57 15.0 N | 81 16 28.0 W | Open | Technology Based | Active | |
| WV1012487 | 081 | 37 57 16.0 N | 81 16 31.0 W | Open | Technology Based | Active | |
| WV1012487 | 082 | 37 57 19.0 N | 81 16 36.0 W | Open | Technology Based | Active | |
| WV1012487 | 083 | 37 57 19.0 N | 81 16 42.0 W | Open | Technology Based | Active | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV1012487 | 084 | 37 57 24.0 N | 81 16 37.0 W | Open | Technology Based | Active | |
| WV1012487 | 085 | 37 57 34.0 N | 81 16 41.0 W | Open | Technology Based | Active | |
| WV1012487 | 086 | 37 57 36.0 N | 81 16 33.0 W | Open | Technology Based | Active | |
| WV1012487 | 087 | 37 57 39.0 N | 81 16 30.0 W | Open | Technology Based | Active | |
| WV1012487 | 088 | 37 57 32.0 N | 81 16 46.0 W | Open | Technology Based | Active | |
| WV1012487 | 089 | 37 57 28.0 N | 81 16 49.0 W | Open | Technology Based | Active | |
| WV1012487 | 090 | 37 57 25.0 N | 81 16 49.0 W | Open | Technology Based | Active | |
| WV1012487 | 091 | 37 56 34.0 N | 81 16 49.0 W | Open | Technology Based | Active | |
| WV1012487 | 092 | 37 56 30.0 N | 81 16 46.0 W | Open | Technology Based | Active | |
| WV1012487 | 093 | 37 56 30.0 N | 81 16 43.0 W | Open | Technology Based | Active | |
| WV1012487 | 094 | 37 56 31.0 N | 81 16 41.0 W | Open | Technology Based | Active | |
| WV1012487 | 095 | 37 56 35.0 N | 81 16 43.0 W | Open | Technology Based | Active | |
| WV1012487 | 096 | 37 56 38.0 N | 81 16 41.0 W | Open | Technology Based | Active | |
| WV1012487 | 097 | 37 56 41.0 N | 81 16 42.0 W | Open | Technology Based | Active | |
| WV1012487 | 098 | 37 56 42.0 N | 81 16 39.0 W | Open | Technology Based | Active | |
| WV1012487 | 099 | 37 56 40.0 N | 81 16 34.0 W | Open | Technology Based | Active | |
| WV1012487 | 100 | 37 56 40.0 N | 81 16 30.0 W | Open | Technology Based | Active | |
| WV1012487 | 101 | 37 56 41.0 N | 81 16 27.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 102 | 37 56 42.0 N | 81 16 22.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 103 | 37 56 40.0 N | 81 16 17.0 W | Open | Technology Based | Active | |
| WV1012487 | 104 | 37 56 44.0 N | 81 16 17.0 W | Open | Technology Based | Active | |
| WV1012487 | 105 | 37 56 47.0 N | 81 16 13.0 W | Open | Technology Based | Active | |
| WV1012487 | 106 | 37 56 51.0 N | 81 16 05.0 W | Open | Technology Based | Active | |
| WV1012487 | 107 | 37 56 54.0 N | 81 56 02.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 108 | 37 56 52.0 N | 81 16 06.0 W | Open | Technology Based | Active | |
| WV1012487 | 109 | 37 56 56.0 N | 81 16 35.0 W | Open | Technology Based | Active | |
| WV1012487 | 110 | 37 57 03.0 N | 81 16 48.0 W | Open | Technology Based | Active | |
| WV1012487 | 111 | 37 56 54.0 N | 81 15 39.0 W | Open | Technology Based | Active | |
| WV1012487 | 112 | 37 56 24.0 N | 81 16 08.0 W | Open | Technology Based | Active | |
| WV1012487 | 113 | 37 56 24.0 N | 81 16 26.0 W | Open | Technology Based | Active | |
| WV1012487 | 114 | 37 56 21.0 N | 81 16 28.0 W | Open | Technology Based | Active | |
| WV1012487 | 115 | 37 56 42.0 N | 81 15 54.0 W | Open | Technology Based | Active | |
| WV1012487 | 116 | 38 57 47.0 N | 81 17 09.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 117 | 38 57 29.0 N | 81 17 16.0 W | Open | Technology Based | Inactive | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV1012487 | 118 | 38 57 19.0 N | 81 17 27.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 119 | 38 57 11.0 N | 81 17 32.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 120 | 38 57 41.0 N | 81 16 42.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 121 | 38 57 59.0 N | 81 16 42.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 122 | 38 57 59.0 N | 81 16 57.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 123 | 38 57 37.0 N | 81 17 09.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 124 | 38 57 22.0 N | 81 17 21.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 125 | 38 56 55.0 N | 81 17 38.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 126 | 38 57 15.0 N | 81 17 07.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 127 | 38 57 33.0 N | 81 17 04.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 128 | 38 57 47.0 N | 81 16 50.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 129 | 38 57 20.0 N | 81 16 47.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 130 | 38 57 12.0 N | 81 16 45.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 131 | 38 56 34.0 N | 81 17 26.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 132 | 38 55 52.0 N | 81 17 19.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 133 | 38 56 05.0 N | 81 16 38.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 134 | 38 56 03.0 N | 81 16 11.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 136 | 38 55 52.0 N | 81 17 19.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 137 | 38 55 45.0 N | 81 17 19.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 138 | 38 55 49.0 N | 81 17 03.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 139 | 38 55 55.0 N | 81 16 59.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 140 | 38 55 55.0 N | 81 16 55.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 141 | 38 56 02.0 N | 81 16 52.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 142 | 38 56 00.0 N | 81 16 35.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 143 | 38 56 03.0 N | 81 16 32.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 144 | 38 55 58.0 N | 81 16 14.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 145 | 37 56 07.0 N | 81 17 14.0 W | Open | Technology Based | Active | |
| WV1012487 | 146 | 37 56 20.0 N | 81 17 07.0 W | Open | Technology Based | Active | |
| WV1012487 | 147 | 37 56 24.0 N | 81 17 02.0 W | Open | Technology Based | Active | |
| WV1012487 | 148 | 37 56 19.0 N | 81 16 50.0 W | Open | Technology Based | Active | |
| WV1012487 | 149 | 37 55 58.0 N | 81 17 10.0 W | Open | Technology Based | Active | |
| WV1012487 | 150 | 37 56 09.0 N | 81 16 48.0 W | Open | Technology Based | Active | |
| WV1012487 | 151 | 37 57 23.0 N | 81 16 54.0 W | Open | Technology Based | Active | |
| WV1012487 | 152 | 37 57 17.0 N | 81 16 53.0 W | Open | Technology Based | Active | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV1012487 | 153 | 37 57 11.0 N | 81 16 57.0 W | Open | Technology Based | Active | |
| WV1012487 | 154 | 37 57 13.0 N | 81 17 06.0 W | Open | Technology Based | Active | |
| WV1012487 | 155 | 37 57 05.0 N | 81 17 04.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 156 | 37 56 58.0 N | 81 17 06.0 W | Open | Technology Based | Active | |
| WV1012487 | 157 | 37 56 53.0 N | 81 17 10.0 W | Open | Technology Based | Active | |
| WV1012487 | 158 | 37 56 52.0 N | 81 17 15.0 W | Open | Technology Based | Active | |
| WV1012487 | 159 | 37 57 00.0 N | 81 17 20.0 W | Open | Technology Based | Active | |
| WV1012487 | 160 | 37 56 55.0 N | 81 17 37.0 W | Open | Technology Based | Active | |
| WV1012487 | 161 | 37 56 49.0 N | 81 17 27.0 W | Open | Technology Based | Active | |
| WV1012487 | 162 | 37 56 57.0 N | 81 17 19.0 W | Open | Technology Based | Active | |
| WV1012487 | 163 | 37 56 51.0 N | 81 17 16.0 W | Open | Technology Based | Active | |
| WV1012487 | 164 | 37 56 52.0 N | 81 17 10.0 W | Open | Technology Based | Active | |
| WV1012487 | 165 | 37 56 57.0 N | 81 17 05.0 W | Open | Technology Based | Active | |
| WV1012487 | 166 | 37 57 04.0 N | 81 17 03.0 W | Open | Technology Based | Active | |
| WV1012487 | 167 | 37 56 42.0 N | 81 16 11.0 W | Open | Technology Based | Active | |
| WV1012487 | 168 | 37 56 31.0 N | 81 17 32.0 W | Open | Technology Based | Inactive | |
| WV1012487 | 169 | 37 56 37.0 N | 81 17 36.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 001 | 38 22 32.0 N | 81 20 05.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 002 | 38 21 51.0 N | 81 19 52.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 003 | 38 21 44.0 N | 81 20 39.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 004 | 38 22 07.0 N | 81 21 05.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 005 | 38 22 21.0 N | 81 21 14.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 006 | 38 22 39.0 N | 81 20 52.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 007 | 38 21 42.0 N | 81 21 15.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 008 | 38 22 53.0 N | 81 19 55.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 009 | 38 02 33.0 N | 81 19 52.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 010 | 38 02 17.0 N | 81 19 54.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 011 | 38 01 51.0 N | 81 20 15.0 W | Open | Technology Based | Inactive | |
| WV1012592 | 012 | 38 01 58.0 N | 81 20 31.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 001 | 37 58 04.0 N | 81 21 23.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 002 | 37 57 33.0 N | 81 20 37.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 003 | 37 58 29.0 N | 81 21 20.0 W | Open | Technology Based | Active | |
| WV1014951 | 004 | 37 58 38.0 N | 81 21 15.0 W | Open | Technology Based | Active | |
| WV1014951 | 005 | 37 58 44.0 N | 81 21 05.0 W | Open | Technology Based | Active | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV1014951 | 006 | 37 58 44.0 N | 81 20 51.0 W | Open | Technology Based | Active | |
| WV1014951 | 007 | 37 58 54.0 N | 81 20 50.0 W | Open | Technology Based | Active | |
| WV1014951 | 008 | 37 59 01.0 N | 81 20 50.0 W | Open | Technology Based | Active | |
| WV1014951 | 009 | 37 58 53.0 N | 81 20 44.0 W | Open | Technology Based | Active | |
| WV1014951 | 010 | 37 58 46.0 N | 81 20 44.0 W | Open | Technology Based | Active | |
| WV1014951 | 011 | 37 58 35.0 N | 81 20 41.0 W | Open | Technology Based | Active | |
| WV1014951 | 012 | 37 58 27.0 N | 81 20 41.0 W | Open | Technology Based | Active | |
| WV1014951 | 013 | 37 58 20.0 N | 81 20 33.0 W | Open | Technology Based | Active | |
| WV1014951 | 014 | 37 58 20.0 N | 81 20 24.0 W | Open | Technology Based | Active | |
| WV1014951 | 015 | 37 57 35.0 N | 81 27 00.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 016 | 37 58 04.0 N | 81 20 15.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 017 | 37 57 55.0 N | 81 20 24.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 018 | 37 57 45.0 N | 81 20 59.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 019 | 37 57 36.0 N | 81 21 09.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 020 | 37 57 32.0 N | 81 21 09.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 021 | 37 57 33.0 N | 81 21 15.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 022 | 37 57 40.0 N | 81 21 27.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 023 | 37 57 37.0 N | 81 21 35.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 024 | 37 57 37.0 N | 81 21 40.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 025 | 37 57 41.0 N | 81 21 35.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 026 | 37 57 45.0 N | 81 21 28.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 027 | 37 57 47.0 N | 81 21 17.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 028 | 37 57 52.0 N | 81 21 08.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 029 | 37 58 00.0 N | 81 21 03.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 030 | 37 58 06.0 N | 81 21 04.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 031 | 37 58 20.0 N | 81 19 17.0 W | Open | Technology Based | Active | |
| WV1014951 | 032 | 37 58 28.0 N | 81 19 26.0 W | Open | Technology Based | Active | |
| WV1014951 | 033 | 37 58 18.0 N | 81 19 14.0 W | Open | Technology Based | Active | |
| WV1014951 | 034 | 37 57 29.0 N | 81 27 09.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 035 | 37 58 11.0 N | 81 20 18.0 W | Open | Technology Based | Active | |
| WV1014951 | 036 | 37 58 13.0 N | 81 20 17.0 W | Open | Technology Based | Active | |
| WV1014951 | 037 | 37 58 14.0 N | 81 20 15.0 W | Open | Technology Based | Active | |
| WV1014951 | 038 | 37 58 23.0 N | 81 19 19.0 W | Open | Technology Based | Active | |
| WV1014951 | 039 | 37 58 14.0 N | 81 20 24.0 W | Open | Technology Based | Active | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV1014951 | 040 | 37 58 17.0 N | 81 20 28.0 W | Open | Technology Based | Active | |
| WV1014951 | 041 | 37 58 48.0 N | 81 20 44.0 W | Open | Technology Based | Active | |
| WV1014951 | 042 | 37 58 38.0 N | 81 21 21.0 W | Open | Technology Based | Active | |
| WV1014951 | 043 | 37 58 35.0 N | 81 19 32.0 W | Open | Technology Based | Active | |
| WV1014951 | 044 | 37 58 08.0 N | 81 21 00.0 W | Open | Technology Based | Inactive | |
| WV1014951 | 045 | 37 58 25.0 N | 81 20 17.0 W | Open | Technology Based | Active | |
| WV1014951 | 046 | 37 58 04.0 N | 81 21 26.0 W | Open | Technology Based | Inactive | |
| WV0028452 | 001 | 37 58 22.0 N | 81 18 17.0 W | Open | Technology Based | Active | |
| WV0028452 | 002 | 37 56 16.0 N | 81 19 19.0 W | Open | Technology Based | Inactive | |
| WV0028452 | 003 | 37 58 07.0 N | 81 18 31.0 W | Open | Technology Based | Active | |
| WV0028452 | 004 | 37 58 20.0 N | 81 18 21.0 W | Open | Technology Based | Active | |
| WV0028452 | 005 | 37 58 15.0 N | 81 18 27.0 W | Open | Technology Based | Active | |
| WV0028452 | 006 | 37 58 33.0 N | 81 18 06.0 W | Open | Technology Based | Active | |
| WV0028452 | 007 | 37 58 15.0 N | 81 18 05.0 W | Open | Technology Based | Inactive | |
| WV0028452 | 008 | 37 57 50.0 N | 81 18 28.0 W | Open | Technology Based | Active | |
| WV0028452 | 009 | 37 57 32.0 N | 81 18 55.0 W | Open | Technology Based | Active | |
| WV0028452 | 010 | 37 56 16.0 N | 81 18 55.0 W | Open | Technology Based | Inactive | |
| WV0028452 | 012 | 37 57 42.0 N | 81 18 53.0 W | Open | Technology Based | Active | |
| WV0028452 | 013 | 37 57 43.0 N | 81 18 48.0 W | Open | Technology Based | Active | |
| WV0028452 | 014 | 37 57 55.0 N | 81 18 44.0 W | Open | Technology Based | Active | |
| WV0028452 | 015 | 37 57 45.0 N | 81 18 46.0 W | Open | Technology Based | Active | |
| WV1002074 | 001 | 37 54 34.0 N | 81 18 11.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 002 | 37 54 45.0 N | 81 18 11.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 003 | 37 54 44.0 N | 81 18 15.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 005 | 37 54 49.0 N | 81 18 19.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 006 | 37 54 55.0 N | 81 18 24.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 007 | 37 54 52.0 N | 81 18 33.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 008 | 37 54 49.0 N | 81 18 41.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 009 | 37 54 55.0 N | 81 18 38.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 014 | 37 54 55.0 N | 81 18 24.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 015 | 37 54 55.0 N | 81 18 24.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 016 | 37 54 55.0 N | 81 18 24.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 017 | 37 54 55.0 N | 81 18 24.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 018 | 37 54 55.0 N | 81 18 24.0 W | Open | Technology Based | Inactive | |

**Table A2.** Discharge Outlets for Paint Creek NPDES Permits.

| NPDES Number | NPDES Outlet | Outlet Latitude | Outlet Longitude | Permit Status | Discharge Limits | Current Activity | Comments |
|---|---|---|---|---|---|---|---|
| WV1002074 | 019 | 37 54 55.0 N | 81 18 24.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 020 | 37 54 55.0 N | 81 18 24.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 021 | 37 54 53.0 N | 81 18 49.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 022 | 37 55 08.0 N | 81 18 36.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 023 | 37 55 02.0 N | 81 18 31.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 024 | 37 55 15.0 N | 81 18 25.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 025 | 37 55 20.0 N | 81 18 16.0 W | Open | Technology Based | Inactive | |
| WV1002074 | 026 | 37 54 39.0 N | 81 17 24.0 W | Open | Technology Based | Active | |
| WV1002074 | 027 | 37 54 51.0 N | 81 17 39.0 W | Open | Technology Based | Active | |
| WV1002074 | 028 | 37 54 56.0 N | 81 17 39.0 W | Open | Technology Based | Active | |
| WV1002074 | 029 | 37 54 44.0 N | 81 17 00.0 W | Open | Technology Based | Active | |
| WV1002074 | 030 | 37 55 26.0 N | 81 17 03.0 W | Open | Technology Based | Active | |
| WV1002074 | 031 | 37 55 32.0 N | 81 17 03.0 W | Open | Technology Based | Active | |
| WV1002074 | 032 | 37 55 12.0 N | 81 17 04.0 W | Open | Technology Based | Active | |
| WV1019317 | 001 | 37 55 12.0 N | 81 17 04.0 W | Open | Technology Based | Inactive | Approximate Location |
| WV1015257 | 002 | 38 00 09.0 N | 81 22 30.0 W | Open | Technology Based | Active | |

**Table A3**. Monthly Reported Discharge Rate for Paint Creek NPDES Outlets.
There are various periods of record for these outlets.

| NPDES Outlet | Jan (gpm) | Feb (gpm) | Mar (gpm) | Apr (gpm) | May (gpm) | Jun (gpm) | Jul (gpm) | Aug (gpm) | Sep (gpm) | Oct (gpm) | Nov (gpm) | Dec (gpm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WV0028452_001 | 83.9 | 103.4 | 123.9 | 102.1 | 118.3 | 122.6 | 60.3 | 45.8 | 63.9 | 58.4 | 60.8 | 55.9 |
| WV0028452_003 | 434.0 | 440.5 | 1156.0 | 906.8 | 640.0 | 599.5 | 192.8 | 193.1 | 153.8 | 136.3 | 178.4 | 199.8 |
| WV0028452_004 | 42.7 | 45.5 | 62.4 | 42.3 | 54.4 | 67.6 | 21.4 | 12.3 | 6.4 | 12.9 | 15.3 | 18.3 |
| WV0028452_005 | 81.2 | 81.2 | 230.0 | 8.0 | 5.5 | 81.2 | 81.2 | 81.2 | 81.2 | 81.2 | 81.2 | 81.2 |
| WV0028452_006 | 4.0 | 3.7 | 6.4 | 3.5 | 1.5 | 10.5 | 2.3 | 3.3 | 2.8 | 3.0 | 2.3 | 2.5 |
| WV1002074_026 | 8.0 | 0.5 | 2.7 | 4.6 | 11.0 | 2.8 | 0.1 | 4.1 | 4.1 | 4.1 | 4.1 | 0.1 |
| WV1002074_028 | 8.0 | 1.0 | 6.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| WV1002074_029 | 0.1 | 0.0 | 0.7 | 0.1 | 0.2 | 0.1 | 0.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.0 |
| WV1002074_030 | 0.5 | 2.7 | 2.5 | 2.7 | 2.7 | 5.0 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| WV1012487_153 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| WV1012487_167 | 1.0 | 2.0 | 5.0 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.0 | 2.0 | 1.0 | 1.0 |
| WV1014951_040 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| WV1014951_037 | 2.5 | 2.5 | 2.5 | 3.0 | 2.0 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| WV1014951_039 | 31.5 | 61.0 | 2.0 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 |
| WV1012487_115 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| WV1002368_002 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| WV0057011_018 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| WV1012487_148 | 49.0 | 105.0 | 95.0 | 49.0 | 50.0 | 102.5 | 25.0 | 20.0 | 10.0 | 61.4 | 37.5 | 132.5 |
| WV1012487_149 | 11.0 | 21.5 | 32.5 | 20.0 | 20.0 | 39.0 | 22.5 | 17.5 | 10.0 | 20.0 | 4.5 | 21.5 |
| WV1012487_051 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| WV1012487_054 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| WV1012487_039 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| WV1012487_050 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 |
| WV1012487_069 | 3.0 | 3.0 | 3.0 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 4.0 | 3.0 | 3.0 |
| WV1012487_087 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 |
| WV1012487_020 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| WV0092142_002 | 75.0 | 15.0 | 29.1 | 10.0 | 59.1 | 59.1 | 3.0 | 1.5 | 340.0 | 59.1 | 59.1 | 59.1 |
| WV1012487_022 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 |
| WV1012487_053 | 3.8 | 3.8 | 3.8 | 2.0 | 2.0 | 7.5 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 |
| WV1012487_063 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| WV1012487_072 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| WV0092142_001 | 3.0 | 2.5 | 2.3 | 2.0 | 1.0 | 3.0 | 2.5 | 1.5 | 5.0 | 2.5 | 1.0 | 2.5 |
| WV1012487_067 | 2.0 | 2.0 | 2.0 | 1.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 3.0 | 2.0 | 2.0 |
| WV1012487_071 | 6.7 | 6.7 | 6.7 | 2.0 | 6.0 | 12.0 | 6.7 | 6.7 | 6.7 | 6.7 | 6.7 | 6.7 |
| WV1012487_049 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| WV1012487_070 | 3.0 | 3.0 | 3.0 | 3.0 | 4.0 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| WV1012487_014 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 32.5 | 7.5 | 10.0 | 16.7 | 16.7 | 16.7 |
| WV1012487_059 | 7.7 | 7.7 | 7.7 | 5.0 | 8.0 | 10.0 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 |
| WV1002368_004 | 12.0 | 17.0 | 20.8 | 13.0 | 15.8 | 16.0 | 6.5 | 15.7 | 15.7 | 15.7 | 15.5 | 21.5 |
| WV1012487_058 | 2.5 | 7.5 | 15.0 | 7.5 | 18.0 | 7.0 | 7.0 | 7.0 | 7.0 | 1.0 | 1.0 | 3.5 |
| WV1012487_083 | 6.5 | 9.0 | 8.8 | 7.0 | 2.0 | 1.0 | 6.0 | 5.0 | 4.0 | 5.8 | 7.3 | 5.8 |
| WV1012487_150 | 46.3 | 66.3 | 89.2 | 48.8 | 40.0 | 37.5 | 35.0 | 31.3 | 45.0 | 80.0 | 50.5 | 53.3 |
| WV1012487_078 | 3.5 | 4.3 | 8.0 | 6.8 | 6.5 | 7.5 | 5.0 | 4.8 | 1.0 | 2.0 | 2.5 | 3.5 |
| WV1012487_076 | 7.0 | 3.3 | 4.8 | 2.3 | 1.5 | 2.3 | 9.3 | 10.0 | 5.0 | 2.0 | 1.0 | 2.0 |
| WV1002066_001 | 27.2 | 25.2 | 18.2 | 17.8 | 16.2 | 20.5 | 7.7 | 5.9 | 9.8 | 10.5 | 10.1 | 14.9 |
| WV1012487_035 | 44.2 | 74.2 | 53.3 | 42.8 | 200.0 | 60.0 | 12.7 | 0.0 | 8.0 | 15.9 | 7.7 | 22.5 |
| WV1012487_005 | 31.5 | 97.5 | 96.7 | 43.0 | 40.8 | 57.5 | 4.0 | 12.0 | 21.5 | 21.0 | 25.2 | 22.0 |
| WV1012487_005 | 31.5 | 97.5 | 96.7 | 43.0 | 40.8 | 57.5 | 4.0 | 12.0 | 21.5 | 21.0 | 25.2 | 22.0 |
| WV1002066_002 | 27.3 | 35.3 | 30.6 | 30.0 | 33.8 | 43.5 | 27.2 | 14.6 | 15.3 | 10.9 | 24.5 | 31.1 |
| WV1012487_024 | 26.4 | 49.4 | 79.4 | 39.8 | 91.7 | 30.9 | 13.3 | 15.0 | 8.8 | 20.0 | 18.0 | 23.4 |
| WV1012487_030 | 43.5 | 45.8 | 78.8 | 47.5 | 97.5 | 42.4 | 16.7 | 30.0 | 11.8 | 16.3 | 6.8 | 19.0 |

**Table A3**. Monthly Reported Discharge Rate for Paint Creek NPDES Outlets.
There are various periods of record for these outlets.

| NPDES Outlet | Jan (gpm) | Feb (gpm) | Mar (gpm) | Apr (gpm) | May (gpm) | Jun (gpm) | Jul (gpm) | Aug (gpm) | Sep (gpm) | Oct (gpm) | Nov (gpm) | Dec (gpm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WV1012487_006 | 57.5 | 137.5 | 100.7 | 85.4 | 116.8 | 65.6 | 27.5 | 20.0 | 27.5 | 54.4 | 40.6 | 43.8 |
| WV1002368_001 | 12.8 | 13.3 | 11.0 | 9.0 | 9.8 | 18.0 | 3.8 | 2.0 | 1.2 | 2.3 | 4.1 | 7.7 |
| WV1012487_027 | 83.9 | 78.5 | 100.8 | 60.6 | 82.0 | 61.6 | 40.0 | 29.4 | 31.8 | 50.5 | 35.2 | 70.3 |
| WV1009311_005 | 70.4 | 74.1 | 64.8 | 100.4 | 79.3 | 116.6 | 67.1 | 58.4 | 55.7 | 60.6 | 46.1 | 55.0 |
| WV1009311_006 | 66.0 | 62.3 | 67.3 | 73.0 | 107.0 | 83.9 | 299.2 | 168.0 | 37.0 | 159.2 | 37.4 | 120.0 |

**Table A4**. Estimated Monthly Average Discharge Rate for Paint Creek NPDES Outlets without observed data. The monthly average discharge rate for these outlets were estimated by multiplying the surface drainage area for the outlet by the estimated local mine drainage rate. The local mine drainage rate (mine outlet drainage rate per unit drainage area) was assumed to be twice the local surface drainage rate, which was calculated from the monthly average flow rate and drainage area for a stream near the mine outlet.

| NPDES Outlet | Jan (gpm) | Feb (gpm) | Mar (gpm) | Apr (gpm) | May (gpm) | Jun (gpm) | Jul (gpm) | Aug (gpm) | Sep (gpm) | Oct (gpm) | Nov (gpm) | Dec (gpm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WV0028452_007 | 3.4 | 3.7 | 4.4 | 3.3 | 2.4 | 1.5 | 1.1 | 1.0 | 0.7 | 1.2 | 1.7 | 1.5 |
| WV0028452_008 | 0.8 | 0.8 | 1.0 | 0.7 | 0.5 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.3 |
| WV0028452_009 | 0.8 | 0.8 | 1.0 | 0.7 | 0.5 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.3 |
| WV0028452_012 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV0028452_013 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV0028452_014 | 3.8 | 4.1 | 4.9 | 3.7 | 2.7 | 1.6 | 1.2 | 1.1 | 0.8 | 1.3 | 1.9 | 1.7 |
| WV0028452_015 | 3.8 | 4.1 | 4.9 | 3.7 | 2.7 | 1.6 | 1.2 | 1.1 | 0.8 | 1.3 | 1.9 | 1.7 |
| WV0057011_003 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV0057011_006 | 3.2 | 3.4 | 4.1 | 3.1 | 2.3 | 1.4 | 1.0 | 0.9 | 0.6 | 1.1 | 1.6 | 1.4 |
| WV0057011_007 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV0057011_008 | 10.3 | 11.2 | 13.4 | 10.0 | 7.4 | 4.4 | 3.2 | 2.9 | 2.1 | 3.6 | 5.2 | 4.6 |
| WV0057011_009 | 22.2 | 24.1 | 28.8 | 21.5 | 15.8 | 9.6 | 6.9 | 6.3 | 4.5 | 7.7 | 11.2 | 9.9 |
| WV0057011_010 | 6.0 | 6.5 | 7.7 | 5.8 | 4.2 | 2.6 | 1.9 | 1.7 | 1.2 | 2.1 | 3.0 | 2.6 |
| WV0057011_011 | 6.4 | 6.9 | 8.2 | 6.1 | 4.5 | 2.7 | 2.0 | 1.8 | 1.3 | 2.2 | 3.2 | 2.8 |
| WV0057011_012 | 26.2 | 28.4 | 33.9 | 25.3 | 18.7 | 11.3 | 8.2 | 7.5 | 5.3 | 9.0 | 13.2 | 11.6 |
| WV0057011_013 | 13.1 | 14.2 | 17.0 | 12.7 | 9.3 | 5.6 | 4.1 | 3.7 | 2.6 | 4.5 | 6.6 | 11.6 |
| WV0057011_014 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV0057011_015 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV0057011_016 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV0057011_017 | 4.8 | 5.2 | 6.2 | 4.6 | 3.4 | 2.1 | 1.5 | 1.4 | 1.0 | 1.6 | 2.4 | 2.1 |
| WV0092142_003 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV0092142_004 | 4.1 | 4.5 | 5.4 | 4.0 | 2.9 | 1.8 | 1.3 | 1.2 | 0.8 | 1.4 | 2.1 | 1.8 |
| WV0096679_001 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1001370_001 | 3.7 | 4.0 | 4.8 | 3.6 | 2.7 | 1.6 | 1.2 | 1.1 | 0.7 | 1.3 | 1.9 | 1.7 |
| WV1002066_003 | 4.4 | 4.8 | 5.6 | 4.0 | 3.2 | 2.0 | 1.2 | 1.2 | 0.8 | 1.6 | 2.0 | 2.0 |
| WV1002066_004 | 3.0 | 3.3 | 3.8 | 2.7 | 2.2 | 1.4 | 0.8 | 0.8 | 0.5 | 1.1 | 1.4 | 1.4 |
| WV1002066_005 | 11.6 | 12.6 | 14.7 | 10.5 | 8.4 | 5.3 | 3.2 | 3.2 | 2.1 | 4.2 | 5.3 | 5.3 |
| WV1002066_006 | 29.7 | 32.4 | 37.8 | 27.0 | 21.6 | 13.5 | 8.1 | 8.1 | 5.4 | 10.8 | 13.5 | 13.5 |
| WV1002074_027 | 0.7 | 0.7 | 0.9 | 0.7 | 0.5 | 0.3 | 0.2 | 0.2 | 0.1 | 0.2 | 0.3 | 0.3 |
| WV1002074_031 | 3.7 | 4.0 | 4.8 | 3.6 | 2.6 | 1.6 | 1.2 | 1.1 | 0.7 | 1.3 | 1.9 | 1.7 |
| WV1002074_032 | 1.0 | 1.1 | 1.3 | 1.0 | 0.7 | 0.4 | 0.3 | 0.3 | 0.2 | 0.3 | 0.5 | 0.5 |
| WV1002368_003 | 25.6 | 27.7 | 33.1 | 24.8 | 18.2 | 11.0 | 8.0 | 7.3 | 5.2 | 8.8 | 12.9 | 11.4 |
| WV1002368_005 | 3.8 | 4.1 | 4.9 | 3.7 | 2.7 | 1.6 | 1.2 | 1.1 | 0.8 | 1.3 | 1.9 | 1.7 |
| WV1009311_004 | 3.3 | 3.5 | 4.2 | 3.2 | 2.3 | 1.4 | 1.0 | 0.9 | 0.7 | 1.1 | 1.6 | 1.5 |
| WV1009311_008 | 1.9 | 2.1 | 2.5 | 1.9 | 1.4 | 0.8 | 0.6 | 0.5 | 0.4 | 0.7 | 1.0 | 0.9 |
| WV1009311_009 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1009311_010 | 1.9 | 2.1 | 2.5 | 1.9 | 1.4 | 0.8 | 0.6 | 0.5 | 0.4 | 0.7 | 1.0 | 0.9 |
| WV1009311_011 | 7.3 | 7.9 | 9.5 | 7.1 | 5.2 | 3.2 | 2.3 | 2.1 | 1.5 | 2.5 | 3.7 | 3.2 |
| WV1009311_012 | 3.1 | 3.3 | 4.0 | 3.0 | 2.2 | 1.3 | 1.0 | 0.9 | 0.6 | 1.1 | 1.5 | 1.4 |
| WV1009311_013 | 0.8 | 0.8 | 1.0 | 0.7 | 0.5 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.3 |
| WV1009311_014 | 0.8 | 0.8 | 1.0 | 0.7 | 0.5 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.3 |
| WV1009311_015 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1009311_017 | 0.8 | 0.8 | 1.0 | 0.7 | 0.5 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.3 |
| WV1009311_018 | 4.2 | 4.6 | 5.5 | 4.1 | 3.0 | 1.8 | 1.3 | 1.2 | 0.9 | 1.5 | 2.1 | 1.9 |
| WV1009311_055 | 4.2 | 4.6 | 5.5 | 4.1 | 3.0 | 1.8 | 1.3 | 1.2 | 0.9 | 1.5 | 2.1 | 1.9 |

**Table A4**. Estimated Monthly Average Discharge Rate for Paint Creek NPDES Outlets without observed data. The monthly average discharge rate for these outlets were estimated by multiplying the surface drainage area for the outlet by the estimated local mine drainage rate. The local mine drainage rate (mine outlet drainage rate per unit drainage area) was assumed to be twice the local surface drainage rate, which was calculated from the monthly average flow rate and drainage area for a stream near the mine outlet.

| NPDES Outlet | Jan (gpm) | Feb (gpm) | Mar (gpm) | Apr (gpm) | May (gpm) | Jun (gpm) | Jul (gpm) | Aug (gpm) | Sep (gpm) | Oct (gpm) | Nov (gpm) | Dec (gpm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WV1012487_003 | 2.1 | 2.3 | 2.7 | 2.0 | 1.5 | 0.9 | 0.7 | 0.6 | 0.4 | 0.7 | 1.1 | 1.0 |
| WV1012487_004 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| WV1012487_007 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_008 | 1.3 | 1.4 | 1.6 | 1.2 | 0.9 | 0.5 | 0.4 | 0.4 | 0.2 | 0.4 | 0.7 | 0.6 |
| WV1012487_009 | 6.4 | 7.0 | 8.2 | 6.1 | 4.6 | 2.7 | 2.1 | 1.8 | 1.2 | 2.1 | 3.4 | 2.9 |
| WV1012487_010 | 2.1 | 2.3 | 2.7 | 2.0 | 1.5 | 0.9 | 0.7 | 0.6 | 0.4 | 0.7 | 1.1 | 1.0 |
| WV1012487_011 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_012 | 3.8 | 4.2 | 4.9 | 3.7 | 2.7 | 1.6 | 1.3 | 1.1 | 0.7 | 1.3 | 2.0 | 1.7 |
| WV1012487_013 | 2.6 | 2.8 | 3.3 | 2.4 | 1.8 | 1.1 | 0.9 | 0.7 | 0.5 | 0.9 | 1.3 | 1.2 |
| WV1012487_015 | 3.4 | 3.7 | 4.4 | 3.2 | 2.4 | 1.5 | 1.1 | 1.0 | 0.6 | 1.1 | 1.8 | 1.5 |
| WV1012487_016 | 2.6 | 2.8 | 3.3 | 2.4 | 1.8 | 1.1 | 0.9 | 0.7 | 0.5 | 0.9 | 1.3 | 1.2 |
| WV1012487_017 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_018 | 43.8 | 47.8 | 55.8 | 39.8 | 31.9 | 19.9 | 12.0 | 12.0 | 8.0 | 15.9 | 19.9 | 19.9 |
| WV1012487_019 | 1.0 | 1.1 | 1.3 | 0.9 | 0.7 | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 |
| WV1012487_021 | 0.5 | 0.5 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| WV1012487_023 | 3.5 | 3.8 | 4.5 | 3.2 | 2.6 | 1.6 | 1.0 | 1.0 | 0.6 | 1.3 | 1.6 | 1.6 |
| WV1012487_025 | 8.1 | 8.8 | 10.3 | 7.3 | 5.9 | 3.7 | 2.2 | 2.2 | 1.5 | 2.9 | 3.7 | 3.7 |
| WV1012487_026 | 1.0 | 1.1 | 1.3 | 0.9 | 0.7 | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 |
| WV1012487_028 | 3.5 | 3.8 | 4.5 | 3.2 | 2.6 | 1.6 | 1.0 | 1.0 | 0.6 | 1.3 | 1.6 | 1.6 |
| WV1012487_029 | 1.0 | 1.1 | 1.3 | 0.9 | 0.7 | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 |
| WV1012487_031 | 2.0 | 2.2 | 2.6 | 1.8 | 1.5 | 0.9 | 0.5 | 0.5 | 0.4 | 0.7 | 0.9 | 0.9 |
| WV1012487_032 | 4.3 | 4.7 | 5.5 | 4.1 | 3.0 | 1.8 | 1.4 | 1.2 | 0.8 | 1.4 | 2.2 | 1.9 |
| WV1012487_033 | 12.4 | 13.5 | 15.9 | 11.8 | 8.8 | 5.3 | 4.1 | 3.5 | 2.4 | 4.1 | 6.5 | 5.6 |
| WV1012487_034 | 3.8 | 4.2 | 4.9 | 3.7 | 2.7 | 1.6 | 1.3 | 1.1 | 0.7 | 1.3 | 2.0 | 1.7 |
| WV1012487_036 | 2.1 | 2.3 | 2.7 | 2.0 | 1.5 | 0.9 | 0.7 | 0.6 | 0.4 | 0.7 | 1.1 | 1.0 |
| WV1012487_037 | 7.3 | 7.9 | 9.3 | 6.9 | 5.2 | 3.1 | 2.4 | 2.1 | 1.4 | 2.4 | 3.8 | 3.3 |
| WV1012487_038 | 1.7 | 1.9 | 2.2 | 1.6 | 1.2 | 0.7 | 0.6 | 0.5 | 0.3 | 0.6 | 0.9 | 0.8 |
| WV1012487_040 | 2.1 | 2.3 | 2.7 | 2.0 | 1.5 | 0.9 | 0.7 | 0.6 | 0.4 | 0.7 | 1.1 | 1.0 |
| WV1012487_041 | 95.5 | 104.6 | 122.8 | 91.0 | 68.2 | 40.9 | 31.8 | 27.3 | 18.2 | 31.8 | 50.0 | 43.2 |
| WV1012487_042 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_043 | 6.0 | 6.6 | 7.7 | 5.5 | 4.4 | 2.7 | 1.6 | 1.6 | 1.1 | 2.2 | 2.7 | 2.7 |
| WV1012487_044 | 6.5 | 7.1 | 8.3 | 6.0 | 4.8 | 3.0 | 1.8 | 1.8 | 1.2 | 2.4 | 3.0 | 3.0 |
| WV1012487_045 | 86.7 | 94.5 | 110.3 | 78.8 | 63.0 | 39.4 | 23.6 | 23.6 | 15.8 | 31.5 | 39.4 | 39.4 |
| WV1012487_046 | 0.5 | 0.5 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| WV1012487_047 | 1.0 | 1.1 | 1.3 | 0.9 | 0.7 | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 |
| WV1012487_048 | 4.0 | 4.4 | 5.1 | 3.7 | 2.9 | 1.8 | 1.1 | 1.1 | 0.7 | 1.5 | 1.8 | 1.8 |
| WV1012487_052 | 3.5 | 3.8 | 4.5 | 3.2 | 2.6 | 1.6 | 1.0 | 1.0 | 0.6 | 1.3 | 1.6 | 1.6 |
| WV1012487_055 | 7.1 | 7.7 | 9.0 | 6.4 | 5.1 | 3.2 | 1.9 | 1.9 | 1.3 | 2.6 | 3.2 | 3.2 |
| WV1012487_056 | 0.5 | 0.5 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| WV1012487_057 | 1.0 | 1.1 | 1.3 | 0.9 | 0.7 | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 |
| WV1012487_060 | 3.0 | 3.3 | 3.8 | 2.8 | 2.1 | 1.3 | 1.0 | 0.9 | 0.6 | 1.0 | 1.6 | 1.4 |
| WV1012487_061 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_062 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_064 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_065 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |

| **Table A4**. Estimated Monthly Average Discharge Rate for Paint Creek NPDES Outlets without observed data. The monthly average discharge rate for these outlets were estimated by multiplying the surface drainage area for the outlet by the estimated local mine drainage rate. The local mine drainage rate (mine outlet drainage rate per unit drainage area) was assumed to be twice the local surface drainage rate, which was calculated from the monthly average flow rate and drainage area for a stream near the mine outlet. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NPDES Outlet** | **Jan (gpm)** | **Feb (gpm)** | **Mar (gpm)** | **Apr (gpm)** | **May (gpm)** | **Jun (gpm)** | **Jul (gpm)** | **Aug (gpm)** | **Sep (gpm)** | **Oct (gpm)** | **Nov (gpm)** | **Dec (gpm)** |
| WV1012487_066 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| WV1012487_068 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_073 | 9.8 | 10.7 | 12.6 | 9.3 | 7.0 | 4.2 | 3.3 | 2.8 | 1.9 | 3.3 | 5.1 | 4.4 |
| WV1012487_074 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| WV1012487_075 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_077 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| WV1012487_079 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_080 | 3.4 | 3.7 | 4.4 | 3.2 | 2.4 | 1.5 | 1.1 | 1.0 | 0.6 | 1.1 | 1.8 | 1.5 |
| WV1012487_081 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_082 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_084 | 9.0 | 9.8 | 11.5 | 8.5 | 6.4 | 3.8 | 3.0 | 2.6 | 1.7 | 3.0 | 4.7 | 4.1 |
| WV1012487_085 | 2.1 | 2.3 | 2.7 | 2.0 | 1.5 | 0.9 | 0.7 | 0.6 | 0.4 | 0.7 | 1.1 | 1.0 |
| WV1012487_086 | 2.1 | 2.3 | 2.7 | 2.0 | 1.5 | 0.9 | 0.7 | 0.6 | 0.4 | 0.7 | 1.1 | 1.0 |
| WV1012487_088 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| WV1012487_089 | 6.4 | 7.0 | 8.2 | 6.1 | 4.6 | 2.7 | 2.1 | 1.8 | 1.2 | 2.1 | 3.4 | 2.9 |
| WV1012487_090 | 3.8 | 4.2 | 4.9 | 3.7 | 2.7 | 1.6 | 1.3 | 1.1 | 0.7 | 1.3 | 2.0 | 1.7 |
| WV1012487_091 | 15.1 | 16.5 | 19.2 | 13.7 | 11.0 | 6.9 | 4.1 | 4.1 | 2.7 | 5.5 | 6.9 | 6.9 |
| WV1012487_092 | 1.0 | 1.1 | 1.3 | 0.9 | 0.7 | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 |
| WV1012487_093 | 3.0 | 3.3 | 3.8 | 2.7 | 2.2 | 1.4 | 0.8 | 0.8 | 0.5 | 1.1 | 1.4 | 1.4 |
| WV1012487_094 | 0.5 | 0.5 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| WV1012487_095 | 0.5 | 0.5 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| WV1012487_096 | 0.5 | 0.5 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| WV1012487_097 | 15.1 | 16.5 | 19.2 | 13.7 | 11.0 | 6.9 | 4.1 | 4.1 | 2.7 | 5.5 | 6.9 | 6.9 |
| WV1012487_098 | 9.6 | 10.4 | 12.2 | 8.7 | 7.0 | 4.4 | 2.6 | 2.6 | 1.7 | 3.5 | 4.4 | 4.4 |
| WV1012487_099 | 1.0 | 1.1 | 1.3 | 0.9 | 0.7 | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 |
| WV1012487_100 | 13.1 | 14.3 | 16.7 | 11.9 | 9.5 | 6.0 | 3.6 | 3.6 | 2.4 | 4.8 | 6.0 | 6.0 |
| WV1012487_101 | 1.0 | 1.1 | 1.3 | 0.9 | 0.7 | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 |
| WV1012487_102 | 6.0 | 6.6 | 7.7 | 5.5 | 4.4 | 2.7 | 1.6 | 1.6 | 1.1 | 2.2 | 2.7 | 2.7 |
| WV1012487_103 | 1.5 | 1.6 | 1.9 | 1.4 | 1.1 | 0.7 | 0.4 | 0.4 | 0.3 | 0.5 | 0.7 | 0.7 |
| WV1012487_104 | 1.5 | 1.6 | 1.9 | 1.4 | 1.1 | 0.7 | 0.4 | 0.4 | 0.3 | 0.5 | 0.7 | 0.7 |
| WV1012487_105 | 4.0 | 4.4 | 5.1 | 3.7 | 2.9 | 1.8 | 1.1 | 1.1 | 0.7 | 1.5 | 1.8 | 1.8 |
| WV1012487_106 | 7.7 | 8.4 | 9.9 | 7.3 | 5.5 | 3.3 | 2.6 | 2.2 | 1.5 | 2.6 | 4.0 | 3.5 |
| WV1012487_108 | 1.3 | 1.4 | 1.6 | 1.2 | 0.9 | 0.5 | 0.4 | 0.4 | 0.2 | 0.4 | 0.7 | 0.6 |
| WV1012487_109 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| WV1012487_110 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_111 | 1.3 | 1.4 | 1.6 | 1.2 | 0.9 | 0.5 | 0.4 | 0.4 | 0.2 | 0.4 | 0.7 | 0.6 |
| WV1012487_112 | 1.5 | 1.6 | 1.9 | 1.4 | 1.1 | 0.7 | 0.4 | 0.4 | 0.3 | 0.5 | 0.7 | 0.7 |
| WV1012487_113 | 2.0 | 2.2 | 2.6 | 1.8 | 1.5 | 0.9 | 0.5 | 0.5 | 0.4 | 0.7 | 0.9 | 0.9 |
| WV1012487_114 | 0.5 | 0.5 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| WV1012487_145 | 2.5 | 2.7 | 3.2 | 2.3 | 1.8 | 1.1 | 0.7 | 0.7 | 0.5 | 0.9 | 1.1 | 1.1 |
| WV1012487_146 | 2.5 | 2.7 | 3.2 | 2.3 | 1.8 | 1.1 | 0.7 | 0.7 | 0.5 | 0.9 | 1.1 | 1.1 |
| WV1012487_147 | 203.5 | 222.0 | 259.1 | 185.0 | 148.0 | 92.5 | 55.5 | 55.5 | 37.0 | 74.0 | 92.5 | 92.5 |
| WV1012487_151 | 2.1 | 2.3 | 2.7 | 2.0 | 1.5 | 0.9 | 0.7 | 0.6 | 0.4 | 0.7 | 1.1 | 1.0 |
| WV1012487_152 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_154 | 1.3 | 1.4 | 1.6 | 1.2 | 0.9 | 0.5 | 0.4 | 0.4 | 0.2 | 0.4 | 0.7 | 0.6 |

**Table A4**. Estimated Monthly Average Discharge Rate for Paint Creek NPDES Outlets without observed data. The monthly average discharge rate for these outlets were estimated by multiplying the surface drainage area for the outlet by the estimated local mine drainage rate. The local mine drainage rate (mine outlet drainage rate per unit drainage area) was assumed to be twice the local surface drainage rate, which was calculated from the monthly average flow rate and drainage area for a stream near the mine outlet.

| NPDES Outlet | Jan (gpm) | Feb (gpm) | Mar (gpm) | Apr (gpm) | May (gpm) | Jun (gpm) | Jul (gpm) | Aug (gpm) | Sep (gpm) | Oct (gpm) | Nov (gpm) | Dec (gpm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WV1012487_155 | 11.1 | 12.1 | 14.3 | 10.6 | 7.9 | 4.8 | 3.7 | 3.2 | 2.1 | 3.7 | 5.8 | 5.0 |
| WV1012487_156 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| WV1012487_157 | 7.7 | 8.4 | 9.9 | 7.3 | 5.5 | 3.3 | 2.6 | 2.2 | 1.5 | 2.6 | 4.0 | 3.5 |
| WV1012487_158 | 7.7 | 8.4 | 9.9 | 7.3 | 5.5 | 3.3 | 2.6 | 2.2 | 1.5 | 2.6 | 4.0 | 3.5 |
| WV1012487_159 | 2.1 | 2.3 | 2.7 | 2.0 | 1.5 | 0.9 | 0.7 | 0.6 | 0.4 | 0.7 | 1.1 | 1.0 |
| WV1012487_160 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| WV1012487_161 | 13.6 | 14.9 | 17.5 | 13.0 | 9.7 | 5.8 | 4.5 | 3.9 | 2.6 | 4.5 | 7.1 | 6.2 |
| WV1012487_162 | 1.7 | 1.9 | 2.2 | 1.6 | 1.2 | 0.7 | 0.6 | 0.5 | 0.3 | 0.6 | 0.9 | 0.8 |
| WV1012487_163 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1012487_164 | 7.3 | 7.9 | 9.3 | 6.9 | 5.2 | 3.1 | 2.4 | 2.1 | 1.4 | 2.4 | 3.8 | 3.3 |
| WV1012487_165 | 2.6 | 2.8 | 3.3 | 2.4 | 1.8 | 1.1 | 0.9 | 0.7 | 0.5 | 0.9 | 1.3 | 1.2 |
| WV1012487_166 | 0.9 | 0.9 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| WV1012487_168 | 9.1 | 9.9 | 11.5 | 8.2 | 6.6 | 4.1 | 2.5 | 2.5 | 1.6 | 3.3 | 4.1 | 4.1 |
| WV1012487_169 | 6.5 | 7.1 | 8.3 | 6.0 | 4.8 | 3.0 | 1.8 | 1.8 | 1.2 | 2.4 | 3.0 | 3.0 |
| WV1012592_011 | 28.4 | 30.5 | 36.7 | 27.0 | 20.1 | 12.5 | 9.0 | 8.3 | 5.5 | 9.7 | 13.9 | 12.5 |
| WV1012592_012 | 40.0 | 42.9 | 51.7 | 38.0 | 28.3 | 17.6 | 12.7 | 11.7 | 7.8 | 13.7 | 19.5 | 17.6 |
| WV1014951_003 | 9.9 | 10.8 | 12.9 | 9.6 | 7.1 | 4.3 | 3.1 | 2.8 | 2.0 | 3.4 | 5.0 | 4.4 |
| WV1014951_004 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1014951_005 | 3.8 | 4.2 | 5.0 | 3.7 | 2.7 | 1.7 | 1.2 | 1.1 | 0.8 | 1.3 | 1.9 | 1.7 |
| WV1014951_006 | 0.8 | 0.8 | 1.0 | 0.7 | 0.5 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.3 |
| WV1014951_007 | 3.8 | 4.2 | 5.0 | 3.7 | 2.7 | 1.7 | 1.2 | 1.1 | 0.8 | 1.3 | 1.9 | 1.7 |
| WV1014951_008 | 1.5 | 1.7 | 2.0 | 1.5 | 1.1 | 0.7 | 0.5 | 0.4 | 0.3 | 0.5 | 0.8 | 0.7 |
| WV1014951_009 | 2.3 | 2.5 | 3.0 | 2.2 | 1.6 | 1.0 | 0.7 | 0.6 | 0.5 | 0.8 | 1.1 | 1.0 |
| WV1014951_010 | 4.6 | 5.0 | 5.9 | 4.4 | 3.3 | 2.0 | 1.4 | 1.3 | 0.9 | 1.6 | 2.3 | 2.0 |
| WV1014951_011 | 0.8 | 0.8 | 1.0 | 0.7 | 0.5 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.3 |
| WV1014951_012 | 6.5 | 7.1 | 8.4 | 6.3 | 4.6 | 2.8 | 2.0 | 1.8 | 1.3 | 2.2 | 3.2 | 2.9 |
| WV1014951_013 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1014951_014 | 2.3 | 2.5 | 3.0 | 2.2 | 1.6 | 1.0 | 0.7 | 0.6 | 0.5 | 0.8 | 1.1 | 1.0 |
| WV1014951_031 | 3.4 | 3.7 | 4.4 | 3.3 | 2.4 | 1.5 | 1.1 | 1.0 | 0.7 | 1.2 | 1.7 | 1.5 |
| WV1014951_032 | 3.6 | 3.9 | 4.6 | 3.4 | 2.5 | 1.5 | 1.1 | 1.0 | 0.7 | 1.2 | 1.8 | 1.6 |
| WV1014951_033 | 3.4 | 3.7 | 4.4 | 3.3 | 2.4 | 1.5 | 1.1 | 1.0 | 0.7 | 1.2 | 1.7 | 1.5 |
| WV1014951_035 | 6.9 | 7.5 | 8.9 | 6.6 | 4.9 | 2.9 | 2.1 | 1.9 | 1.4 | 2.4 | 3.4 | 3.1 |
| WV1014951_036 | 0.4 | 0.4 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| WV1014951_038 | 3.4 | 3.7 | 4.4 | 3.3 | 2.4 | 1.5 | 1.1 | 1.0 | 0.7 | 1.2 | 1.7 | 1.5 |
| WV1014951_041 | 1.9 | 2.1 | 2.5 | 1.8 | 1.4 | 0.8 | 0.6 | 0.5 | 0.4 | 0.7 | 1.0 | 0.8 |
| WV1014951_042 | 3.4 | 3.7 | 4.5 | 3.3 | 2.5 | 1.5 | 1.1 | 1.0 | 0.7 | 1.2 | 1.7 | 1.5 |
| WV1014951_043 | 98.8 | 107.4 | 127.4 | 95.2 | 70.2 | 42.2 | 30.8 | 27.9 | 20.0 | 33.6 | 49.4 | 44.0 |
| WV1014951_045 | 4.2 | 4.6 | 5.5 | 4.1 | 3.0 | 1.8 | 1.3 | 1.2 | 0.9 | 1.5 | 2.1 | 1.9 |
| WV1015257_002 | 68.0 | 74.2 | 88.1 | 64.9 | 47.9 | 29.4 | 21.6 | 18.6 | 13.9 | 23.2 | 34.0 | 30.2 |
| WV1019317_001 | 1.0 | 1.1 | 1.3 | 1.0 | 0.7 | 0.4 | 0.3 | 0.3 | 0.2 | 0.3 | 0.5 | 0.5 |

**Table A5**. NPDES Net Acidity and Metal Concentrations for Base Conditions Model.

| Water Quality Constituent | Concentration (mg/L) |
|---|---|
| Net Acidity* | 0.14 |
| Total Iron | 3.20 |
| Manganese | 2.00 |
| Total Aluminum | 4.30 |

*Net Acidity = 0.14 corresponds for pH = 6.

## APPENDIX B. Theoretical Basis of the *TAMDL* computer program

### Introduction

The computer program *TAMDL* is designed to simulate those aspects of a watershed's stream water quality affected by acidic mine drainage. The current version of *TAMDL* simulates water temperature, net acidity, proton concentration (pH), ferrous iron, ferric iron, manganese, aluminum and dissolved oxygen. Water quality conditions are simulated by numerically solving the advection, dispersion, loading and reaction partial differential equation for each of these constituents. The effect of the advection and dispersion terms on the concentration and temperature of the stream at each model node are solved using the explicit MacCormack predictor – corrector finite difference method. The loading and reaction terms in the governing equations are solved using the fourth order Runge-Kutta method.

Because *TAMDL* uses net acidity to simulate the solution buffering, the governing partial differential equation is not used to calculate the proton concentration. Rather an empirical net acidity – pH model is employed to calculate the proton concentration each time step. The increase in proton concentration caused by the chemical reactions being simulated is translated into a corresponding increase in net acidity. The constituents simulated by the program are listed in Table B1.

Table B1. Water Quality Constituents Simulated by *TAMDL*.

| Number | Water Quality Constituent | Symbol | Units |
|---|---|---|---|
| 1 | Stream Temperature | T | °C |
| 2 | Net Acidity Concentration | A | mg/l $CaCO_3$ |
| 3 | Proton Molar Concentration | $[H^+]$ | M |
| 4 | Ferrous Iron Concentration | $Fe^{2+}$ | mg/l |
| 5 | Ferric Iron Concentration | $Fe^{3+}$ | mg/l |
| 6 | Manganese Concentration | $Mn^{2+}$ | mg/l |
| 7 | Total Aluminum Concentration | $Al^{3+}$ | mg/l |
| 8 | Dissolved Oxygen Concentration | $O_2$ | mg/l |

### Governing Equations

The following partial differential equation is solved by *TAMDL* for each water quality constituent, except for proton concentration.

$$\frac{\partial C_i}{\partial t} = m\frac{\partial^2 C_i}{\partial x^2} - V\frac{\partial C_i}{\partial x} + L_i + S_i \qquad (1)$$

Where: $C_i$ = Water quality constituent vector.
$x$ = Distance downstream.

| | | |
|---|---|---|
| $V$ | = | Stream velocity. |
| $L_i$ | = | Nodal source (sink) loading term. |
| $S_i$ | = | Chemical and physical reaction source (sink) term(s). |
| $i$ | = | Constituent index corresponding to rows of Table B1. |
| $m$ | = | Hydrodynamic dispersion. |

As was mentioned above, the governing equation for the proton concentration is the empirical algebraic net acidity – pH model.

$$pH = -\log_{10}(C_3) = c_1 \max\left(1, C_2^2\right)^{c_2 \,\mathrm{sign}(C_2)} \qquad (2)$$

| Where: | | | | |
|---|---|---|---|---|
| | $C_3$ | = | Proton Concentration, mole/L. | |
| | $C_2$ | = | Net Acidity, g/m$^3$ $CaCO_3$ equivalent. | |
| | sign$(C_2)$ | = | -1, | net alkaline conditions ($C_2 < 0$). |
| | | = | 0, | neutral conditions ($C_2 = 0$). |
| | | = | +1, | net acidic conditions ($C_2 > 0$). |
| | $c_1$, $c_2$ | = | Watershed specific empirical constants. | |

The watershed specific empirical constants in the net acidity – pH model are best determined by statistically fitting the model to the measured net acidity and pH data from samples collected in the watershed being simulated. If no data is available, Stiles and Fripp (2000) presented values for these constants obtained from data collected from several watersheds in West Virginia, Maryland and Pennsylvania.

The magnitude of the loading source (sink) term is specified by the user for each parameter and model node throughout the simulation. This loading is expressed by the user as a function of the simulation time. Normally acidic loading (i.e. the acidic drainage from a mine portal) is specified as a positive loading of net acidity. Alkaline treatment of stream water is specified as a negative loading of net acidity.

The loading of some important water quality parameters can be a function of the local runoff. The reduction of net acidity near a site containing alkaline materials would be a direct function of the local runoff. For this to be adequately modeled the loading must be calculated be either by a specially designed subroutine or an external program before the simulation.

The chemical and physical reactions modeled by *TAMDL* are listed below in Tables B2 and B3. The source (sinks) for each constituent are calculated by algebraically summing the consumption and production rates for each of the modeled chemical and physical reactions.

Table B2. Chemical Reactions Simulated by *TAMDL*.

| Chemical Reaction | Consumes | Produces |
|---|---|---|
| Ferrous Iron Oxidation | $O_2$, $Fe^{2+}$ | $Fe^{3+}$, $H^+$ |
| Manganese Oxidation and Precipitation | $O_2$, $Mn^{2+}$ | $H^+$ |
| Aluminum Precipitation | $Al^{2+}$ | $H^+$ |
| Organic Material Decay | $O_2$ | – |

Table B3. Physical Reactions Simulated by *TAMDL*.

| Physical Reaction | Consumes | Produces |
|---|---|---|
| Aeration | – | $O_2$ |
| Meteorological Heating | – | T |
| Ferric Iron Sedimentation | $Fe^{3+}$ | – |

**Ferrous Iron Oxidation**

The computer program *TAMDL* uses the following chemical reaction to calculate the molar quantities of the constituents consumed and produced by ferrous iron oxidation. When the stream is effectively anoxic, $C_8 < 0.01$ g/m$^3$, the oxidation of ferrous iron is neglected.

$$Fe^{2+} + \frac{1}{4}O_2 + \frac{5}{2}H_2O \rightarrow Fe(OH)_3 + 2H^+ \tag{3}$$

The following kinetic equation is used by the program for calculating the rate in which ferrous iron is being consumed both by abiotic and biotic oxidation. The rate in which dissolved oxygen is being consumed and the rate in which ferric iron and protons are being produced is determined from the stoichmetry presented in equation (3). This kinetic formulation was presented by Kirby, Thomas, Southam and Donald (1998).

$$\begin{aligned} R_4 = &-3.125117192 \times 10^{-5} A_{abiotic} \exp\left(\frac{-E_{abiotic}}{R\,(C_1 + 273)}\right) C_4\, C_8\, C_3^{-2} \\ &- 3.125117192 \times 10^{-5} A_{biotic} \exp\left(\frac{-E_{biotic}}{R\,(C_1 + 273)}\right) C_4 C_{ferro}\, C_8 C_3 \end{aligned} \tag{4}$$

Where:

| | | |
|---|---|---|
| $C_4$ | = | Ferrous Iron Concentration, g/m$^3$. |
| $R_4$ | = | Ferrous Iron Oxidation Rate, g/m$^3$/day. |
| $C_8$ | = | Dissolved Oxygen Concentration, mg/L. |
| $C_3$ | = | Proton Molar Concentration, M. |
| $C_1$ | = | Stream Temperature, C. |
| $A_{abiotic}$ | = | Empirical Chemical Rate Constant; |
| | = | $3.4560 \times 10^{10}$ mole/L/day. |
| $E_{abiotic}$ | = | Empirical Chemical Rate Constant; |

| | | |
|---|---|---|
| | = | 96 kJ/mole. |
| $R$ | = | Universal Gas Constant; |
| | = | $8.314 \times 10^{-3}$ kJ/mole/K. |
| $C_{ferro}$ | = | *T. Ferrooxidans* dry mass concentration, g/m$^3$. |
| $A_{biotic}$ | = | Empirical Biological Rate Constant. |
| | = | $8.8128 \times 10^{13}$ mole/L/day. |
| $E_{biotic}$ | = | Empirical Biological Rate Constant. |
| | = | 58.77 kJ/mole. |

**Ferric Iron Sedimentation**

*TAMDL* assumes that once the ferrous iron is oxidized to ferric iron, it immediately joins with dissolved oxygen to form ferric oxide. Ferric oxide leaves the computational domain by clinging to sediment particles in the stream and settling to the channel bottom. The re-suspension of the sediment particles with the attached ferric oxide is not simulated by *TAMDL*. The velocity that the sediment particles fall to the bottom of the channel is governed by Stokes Law. Stokes law requires that the particle Reynolds number (calculated with the particle diameter) be less than one (Roberson and Crowe, 1980). For the sediment particles most likely to carry ferric oxide, this assumption is quite reasonable. With the hydraulic depth, the settling velocity can be used to calculate the ferric iron sedimentation rate.

$$R_5 = -\frac{V_S C_5}{D} \tag{5}$$

Where:

| | | |
|---|---|---|
| $R_5$ | = | Ferric iron sedimentation rate, g/m$^3$/day. |
| $C_5$ | = | Ferric iron concentration, g/m$^3$. |
| $V_S$ | = | Sediment settling velocity m/day. |
| $D$ | = | Hydraulic depth of the stream, m. |
| | = | Stream flow area / top width. |

The following is the equation for the settling velocity that was derived from Stokes' Law.

$$V_S = \frac{4.0684 \times 10^9 (S_g - 1) D_S^2}{n} \tag{6}$$

Where:

| | | |
|---|---|---|
| $S_g$ | = | Specific weight of the sediment particles. |
| | = | Assumed by *TAMDL* to be 2.5. |
| $D_S$ | = | Diameter of the sediment particles, m. |
| $n$ | = | Kinematic viscosity of water, m$^2$/day. |

Because the kinematic viscosity for water changes as the temperature changes, the following polynomial regression formula is used to calculate the kinematic viscosity from the stream temperature.

$$
\begin{aligned}
n = {} & 1.25952x10^{-10}(C_1+273)^6 - 2.226642x10^{-7}(C_1+273)^5 \\
& + 0.0001639532(C_1+273)^4 - 0.06436165(C_1+273)^3 \\
& + 14.20698(C_1+273)^2 - 1671.963(C_1+273) + 81960.09
\end{aligned} \tag{7}
$$

**Manganese Oxidation and Precipitation**

The formulation *TAMDL* employs to calculate the rate of manganese oxidation and precipitation was obtained from Stumm and Morgan (1981). Stoichmetry is defined by the program using the following chemical reaction. When the stream is effectively anoxic, $C_8$ < 0.01 g/m$^3$, manganese oxidation and precipitation is neglected.

$$
Mn^{2+} + H_2O + \frac{1}{2}O_2 \rightarrow MnO_2 + 2H^+ \tag{8}
$$

The following equation is an expression of the kinetic rate equation in terms of mass concentrations.

$$
R_6 = \frac{-a_6 C_6 C_8 C_5}{C_3^2} \exp\left(\frac{-E_6}{R(C_1+273)}\right) \tag{9}
$$

| | | | |
|---|---|---|---|
| Where: | $R_6$ | = | Manganese precipitation and oxidation rate, g/m$^3$/day. |
| | $C_6$ | = | Manganese concentration, g/m$^3$. |
| | $C_8$ | = | Dissolved oxygen concentration, g/m$^3$. |
| | $C_5$ | = | Ferric iron concentration, g/m$^3$. |
| | $C_3$ | = | Proton concentration, mole/L. |
| | $a_6$ | = | User specified rate constant, L$^4$/(mg$^4$-day). |
| | $E_6$ | = | Empirical rate constant, 107.987 kJ/mole. |
| | $R$ | = | Universal gas constant, 8.314 x 10$^{-3}$ kJ/mole/K. |

**Aluminum Precipitation**

The chemical reaction for aluminum precipitation is similar to the equation for manganese oxidation and precipitation except for the absence of oxidation because aluminum has only a single oxidation state. Likewise, the kinetic formulation for aluminum precipitation is similar to the kinetic formulation for abiotic ferrous oxidation.

$$
Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+ \tag{10}
$$

$$R_7 = \frac{-a_7 C_7 A_7}{C_3^3} \exp\left(\frac{-E_7}{R\,(C_1 + 273)}\right) \qquad (11)$$

Where: $C_7$ = Aluminum concentration, g/m$^3$.
$R_7$ = Aluminum precipitation rate, g/m$^3$/day.
$a_7$ = User specified empirical rate constant, dimensionless.
$E_7$ = Empirical rate constant, 58.2 kJ/mole.
$A_7$ = Empirical rate constant, 3160 mole$^3$/L$^3$/day.

If the user specifies a negative value for the empirical rate constant, $a_7$, then *TAMDL* does not calculate the aluminum precipitation rate and restricts the aluminum concentration to the solubility limit for aluminum. The maximum aluminum concentration possible under equilibrium conditions, $C_7^{equil}$, is given by the following equation.

$$C_7^{equil} = \exp\left(35.071 + 6.9078 \log_{10}(C_3)\right) \qquad (12)$$

**Stream Reaeration and Organic Material Decay**

The simulated dissolved oxygen concentration is affected by stream reaeration and the decay of organic material. Stream reaeration is assumed to be a function of the mean stream velocity, $V$, and the difference between the dissolved oxygen saturated concentration, $C_{sat}$, and the concentration, $C_8$, O'Conner and Dobbins (1958). The affect of organic material decay on the dissolved oxygen concentration is simulated by *TAMDL* using a zeroth order sediment oxygen demand formulation adapted from the lake model *CE-QUAL-W2* (Cole and Buchak, 1995). The sediment oxygen demand per model node, $k_{SOD}$, is a constant specified by the user for all of the nodes in the entire computational domain. When the stream is nearly anoxic, $C_8$ < 1.0 g/m$^3$, sediment oxygen demand is neglected. While the growth (decay) of algae is a common source (sink) of dissolved oxygen for streams, *TAMDL* assumes that algal growth in streams affected by AMD is negligible. Although dissolved oxygen can be a limiting factor in ferrous oxidation and manganese oxidation and precipitation, the precise simulation of dissolved oxygen is not crucial to the modeling of most streams affected by AMD. The following set of equations is the complete formulation the program uses to calculate sources (sinks) of dissolved oxygen.

$$R_8 = \frac{k_{SOD}}{R} + 1.023^{C_1 - 25} k_8 \left(C_{SAT} - C_8\right) \qquad (13)$$

$$\begin{aligned} k_8 &= 6.0804 \times 10^{-5} \frac{V}{D^{5/3}}, \text{when } V < 42340 \text{ m/day} \\ k_8 &= 0.013376 \frac{V^{1/2}}{D^{3/2}}, \text{when } V \geq 42340 \text{ m/day} \end{aligned} \qquad (14)$$

Where: $R_8$ = Dissolved oxygen rate of production, g/day.
$C_8$ = Dissolved oxygen concentration, g/m$^3$.
$k_{SOD}$ = Sediment oxygen demand per model node, g/m$^3$/day.
$R$ = Hydraulic radius, m.
= Stream flow area / wetted channel perimeter.
$C_{SAT}$ = Saturated dissolved oxygen concentration, g/m$^3$.
$k_8$ = O'Conner-Dobbins aeration rate constant, 1/day.
$D$ = Hydraulic depth of the stream, m.
= Stream flow area / top width.

The dissolved oxygen saturated concentration is calculated with the following regression formula derived from the saturated concentration values obtained from Tchobanoglous (1991).

$$\begin{aligned} C_{SAT} = &-0.0005158(C_1+273)^3+0.04958(C_1+273)^2 \\ &-15.94(C_1+273)+1721 \end{aligned} \tag{15}$$

**Meteorological Heating**

In order to account for the affect of weather on the stream temperature, *TAMDL* simulates the heating and cooling of the stream due to its contact with the atmosphere. Although the stream temperature has some affect on the rate of oxidation and precipitation of ferrous iron, manganese and aluminum, the precise simulation of stream temperature is not crucial to the modeling of streams affected by AMD. The simplified formulation used by the program assumes that the amount of heat transferred the atmosphere is proportional to the difference in temperature and the wind speed, and inversely proportional to the mean depth of flow across the channel.

$$R_1 = \frac{K_1 W\left(T_{AIR} - C_1\right)}{D} \tag{16}$$

Where: $R_1$ = Thermal energy gained (lost), calories/day.
$C_1$ = Stream temperature, C.
$W$ = Wind speed, m/day.
$T_{air}$ = Air Temperature, C.
$D$ = Hydraulic depth, m.
$K_1$ = Convective Heat Transfer Coefficient.
» 1.0 x 10$^{-5}$ calories/K

**Stoichmetric Considerations**

The aforementioned reactions must be modeled simultaneously because one water quality constituent can be produced by one reaction and consumed by another reaction. Furthermore, a single reaction may consume and produce several constituents. Therefore, the elements of the source term in equation (1) are defined by the following stoichmetric relationships. If the user has specified that the aluminum precipitation be controlled by the aluminum equilibrium relationship, equation (12), the acidity contribution of aluminum precipitation is included in a separate portion of the model. The empirical net acidity – pH relationship is used to express increases in proton concentration in terms of increases in acidity.

$$S_1 = R_1 \tag{17}$$

$$S_2 = \frac{\mathrm{sign}(C_2)\,\max(1,|C_2|)\,\exp\left(\ln(10)\,c_1 \max(1,{C_2}^2)^{c_2\,\mathrm{sign}(C_2)}\right)}{2\ln(10)\,c_1\,c_2 \max(1,{C_2}^2)^{c_2\,\mathrm{sign}(C_2)}} S_2' \tag{18}$$

$$S_2' = \frac{2}{55847.0} R_4 + \frac{2}{54938.0} R_6 + \frac{3}{26981.54} R_7 \tag{19}$$

$$S_3 = 0 \tag{20}$$

$$S_4 = R_4 \tag{21}$$

$$S_5 = R_5 - R_4 \tag{22}$$

$$S_6 = R_6 \tag{23}$$

$$S_7 = R_7 \tag{24}$$

$$S_8 = R_8 + \left(\frac{1}{4}\right)\left(\frac{31.9988}{55.847}\right) R_4 + \left(\frac{1}{2}\right)\left(\frac{31.9988}{54.9380}\right) R_6 \tag{25}$$

**Boundary and Initial Conditions**

Upstream of the computational domain for each simulation, the user specifies the boundary temperature and concentrations. The specified upstream boundary temperature and concentrations may vary with simulation time. Normally, the upstream boundary condition is calculated from the results of the model for the upstream sub-watershed. If there is no upstream sub-watershed, the upstream boundary condition must be implied from the results of water quality sampling.

At the downstream end of each computational domain, *TAMDL* assumes that the spatial gradient of the temperature and concentration is zero. Downstream boundary condition required because of the dispersion (second derivative) term in governing equations. If there is no flow through the computational domain, *TAMDL* automatically applies the downstream boundary condition to the upstream boundary. The concentrations specified for the upstream boundary are ignored.

*TAMDL* requires that the initial temperature and concentration be specified for each node. Initial conditions are not very important when one desires a steady state solution. When one is simulating a transient problem, the precise selection of initial conditions may have an important effect on the results calculated in the early portion of the simulation. Realistic initial conditions can be generated by simulating water quality conditions for a period prior to the desired simulation period.

**Nodal Source Loading**

The nodal source loading term, $L_i$, in equation (1), *TAMDL*'s governing partial differential equation is specified by the user for one or more of the simulation's model nodes. The fields, which must be specified in source loading section of the input data file, are listed in Table B4.

Table B4. Source Loading Data Fields.

| Field | Description | Model Units |
|---|---|---|
| 1 | Model node to apply load. | —— |
| 2 | Thermal load. | J/day |
| 3 | Net acidity load. | g/day $CaCO_3$ |
| 4 | Alkalinity production rate constant. | $day^{-1}$ |
| 5 | Ferrous iron load. | g/day |
| 6 | Ferric iron load. | g/day |
| 7 | Manganese load. | g/day |
| 8 | Total aluminum load. | g/day |
| 9 | Dissolved oxygen load. | g/day |
| 10 | Start Time for this load. | day |
| 11 | Ending time for this load. | day |

Because the empirical net acidity – pH relationship, equation (2), is used by *TAMDL* is used to calculate the pH from the simulated stream net acidity, proton molar loading is not needed by the program. The alkalinity production constant is used to determine the alkalinity being generated at any given simulation time from either naturally occurring or placed limestone in the stream channel. Because the alkalinity being produced by the limestone is directly proportional to the net acidity of the stream, the resulting net acidity being applied to a particular model node is calculated with equation (26).

$$L_3 = L_3' - L_4'\left(C_3 - C_3^{sat}\right) \qquad (26)$$

Where: $L_3$ = Total net acidity application rate.

| | | |
|---|---|---|
| $L_3'$ | = | Constant net acidity application rate. |
| $L_4'$ | = | Alkalinity production rate constant. |
| $C_3$ | = | Net acidity of the stream. |
| $C_3^{sat}$ | = | Net acidity of solution saturated with limestone, mg/L $CaCO_3$. |

Experiments have shown that it is impossible under atmospheric conditions to raise the pH of a solution above 8.3 with the application of limestone. Therefore, the net acidity of a solution saturated with limestone is calculated with the empirical net acidity – pH relationship. Under certain circumstances, the application of equation (26) by *TAMDL* can result in numerical oscillation in the calculated net acidity concentration. Therefore, some caution should be observed in interpreting the results of a simulation of a stream with limestone in the channel at one or more model nodes.

**Model Hydrology**

The advection (first spatial derivative) term in equation (1), the governing partial differential equation, requires that the mean stream flow velocity be a known quantity at all locations in the model domain. Since the efficient numerical algorithm employed by *TAMDL* in solving the governing equation requires that both the velocity and the dispersion coefficient remain uniform throughout the model domain, the program requires that the watershed be divided into several sub-watersheds. Where two tributaries meet, the program applied continuity in order to calculate the upstream boundary conditions for the lower sub-watershed.

A TMDL study with unlimited funding would undoubtedly use a dedicated hydrologic software package to simulate the basin's water budget and calculate the mean stream flow velocity for each sub-watershed. Modifying *TAMDL* to read the results of a dedicated hydrologic package would not be difficult; however, few watersheds possess the quantity of hydrologic data required to warrant such a sophisticated analysis.

Because a sophisticated hydrologic analysis is rarely warranted, the current version of *TAMDL* assumes normal flow throughout the domain, unless the user, for testing purposes, has specified a constant depth of flow. Stream channels are also assumed to be prismatic trapezoids with a rectangular flood plain. Equation (27), Manning's equation is used by the program to iteratively calculate the mean velocity from the bottom slope and the hydraulic elements calculated with equations (28) and (29).

$$V = \frac{f}{n}\left(\frac{A}{P}\right)^{2/3}\sqrt{S_o} \qquad (27)$$

$$A = \left(b + z\min(h,h_b)\right)\min(h,h_b) + b_f\max(0,h - h_b) \qquad (28)$$

$$P = b + 2\min(h,h_b)\sqrt{1 + z^2} + \mathrm{u}(h - h_b)(b_f - b - 2(z+1)h_b + 2h) \qquad (29)$$

| | | | |
|---|---|---|---|
| Where: | $h$ | = | Depth of stream flow. |
| | $h_b$ | = | Depth of the bank of the main trapezoidal channel. |
| | $b$ | = | Bottom width of main trapezoidal channel. |
| | $b_f$ | = | Width of rectangular flood plain. |
| | $z$ | = | Inverse slope of the main trapezoidal channel sides. |
| | $A$ | = | Total cross sectional area of the stream flow. |
| | $P$ | = | Total wetted perimeter of the stream. |
| | $n$ | = | Manning's roughness coefficient. |
| | $S_o$ | = | Bottom slope of the main trapezoidal channel bottom. |
| | $f$ | = | Manning unit conversion constant. |
| | | = | 1.00, if SI units are employed. |
| | | = | 1.49, if US customary units are employed. |

In order for one value of Manning's roughness coefficient to be valid across a large range of discharge rates, the stream must be in the fully rough region of the turbulent regime. This condition is checked by the hydraulics subroutine in *TAMDL* with the criterion presented by Henderson (1966). When this criterion is not being satisfied, a warning message is printed in the log output file. Equation (30) is the non-dimensional form of the fully rough criterion.

$$\frac{g^{3.5}n^6}{f^6\boldsymbol{n}}\sqrt{RS} > 2.82 \text{ x } 10^{-4} \qquad (30)$$

| | | | |
|---|---|---|---|
| Where: | $g$ | = | Acceleration due to gravity. |
| | $\boldsymbol{n}$ | = | Kinematic viscosity. |

Because *TAMDL* uses SI units exclusively for hydraulic calculations, equation (30) can be further simplified to yield equation (31). Equation (31) requires that the temperature of the stream is approximately 20 °C.

$$n^6\sqrt{RS} > 9.54 \text{ x } 10^{-14} \qquad (31)$$

**Selection of Numerical Algorithm**

Because the *TAMDL* will normally be executed on an Intel based personal computer, efficient use of computational resources is very important. Therefore, the appropriate numerical algorithm should be both explicit and at least second order accurate in both time and space. One well tested algorithm that satisfies this requirement is the explicit MacCormack Predictor – Corrector method (Anderson, Tannehill and Pletcher, 1984). Because this finite difference algorithm is normally applied to the solution of the advection – dispersion equation, the loading and chemical reaction terms in the governing equation must be solved analytically or with a numerical technique for first order ordinary differential equations.

Because the equations describing the kinetic rates of the aforementioned reactions are both complex and non-linear, it was decided that both the loading and reaction terms should be solved numerically. First order ordinary differential equations are commonly solved with one of the Runge-Kutta methods (Boyce and DiPrima, 1977). In order to make the simplify the *TAMDL* source code, it was decided that intermediate time steps to solve the chemical reaction and loading terms would not be employed. Therefore, to achieve the desirable accuracy, it was decided to use the fourth order Runge-Kutta method to solve the contributions of these terms to the temporal change in concentration.

### Explicit MacCormack Predictor – Corrector Method

Because this method is explicit, *TAMDL* is not required to solve a matrix during each simulated time step. Instead, a predictor and corrector step are calculated every time step. The formulas for the predictor step are shown in equations (32) and (33).

$$F_{i,j}^{n} = V C_{i,j}^{n} \tag{32}$$

$$P_{i,j}^{n} = C_{i,j}^{n} - \frac{\Delta t}{\Delta x}\left(F_{i+1,j}^{n} - F_{i,j}^{n}\right) + \frac{m\,\Delta t}{(\Delta x)^2}\left(C_{i+1,j}^{n} - 2C_{i,j}^{n} + C_{i-1,j}^{n}\right) \tag{33}$$

Where:

| | | | |
|---|---|---|---|
| Where: | $C_{i,j}^{n}$ | = | Concentration of the *j* water quality parameter at the *i* model node at the *n* time step. |
| | $P_{i,j}^{n}$ | = | Predicted value of concentration for next time step. |
| | $F_{i,j}^{n}$ | = | Advection of *j* water quality parameter at the *i* model node at the *n* time step. |
| | $m$ | = | Hydrodynamic dispersion of constituents. |
| | $Dt$ | = | Size of the current time step. |
| | $Dx$ | = | Distance between model nodes. |

The predicted concentration for the *n+1* time step is used in equation (34) and (35) to calculate the corrected concentration for the *n+1* time step. The net effect of the chemical reaction and loading terms on the concentration will be added to the corrected concentration.

$$G_{i,j}^{n} = V P_{i,j}^{n} \tag{34}$$

$$\hat{C}_{i,j}^{n+1} = \frac{1}{2}\left[C_{i,j}^{n} + P_{i,j}^{n} - \frac{\Delta t}{\Delta x}\left(G_{i,j}^{n} - G_{i-1,j}^{n}\right) + \frac{m\,\Delta t}{(\Delta x)^{2}}\left(P_{i+1,j}^{n} - 2P_{i,j}^{n} + P_{i-1,j}^{n}\right)\right] \qquad (35)$$

Where: $G_{i,j}^{n}$ = Advection of *j* predicted water quality parameter at *i* model node at the *n* time step.

$\hat{C}_{i,j}^{n+1}$ = Corrected concentration for the next time step.

Upstream and downstream boundary conditions are applied by changing the predictor and corrector formulas for the first and last model nodes to reflect the appropriate conditions.

**Fourth Order Runge-Kutta Method**

The fourth order Runge-Kutta method was selected because of both its familiarity and low truncation error. The small magnitude of truncation error, Ø($\Delta t^5$), is important because the time step is best controlled by the Explicit MacCormack method's stability criteria and *TAMDL* does not use intermediate time steps in evaluating the effects of the reaction and loading terms. The program adds the contribution of the loading and chemical reaction terms to the corrected concentration for the next time step using the equation (36). The weighted estimated average of the loading and kinetic rates during the time step are calculated by equations (37), (38), (39) and (40). Summation notation is not employed in these equations, and the parenthesis is used to indicate functional relationship, not multiplication.

$$C_{i,j}^{n+1} = \hat{C}_{i,j}^{n+1} + \frac{\Delta t}{6}\left(H_{i,j} + 2I_{i,j} + 2J_{i,j} + K_{i,j}\right) \qquad (36)$$

$$H_{i,j} = S_{i,j}\left(\hat{C}_{i,j}^{n+1}\right) \qquad (37)$$

$$I_{i,j} = S_{i,j}\left(\hat{C}_{i,j}^{n+1} + \frac{\Delta t}{2} H_{i,j}\right) \qquad (38)$$

$$J_{i,j} = S_{i,j}\left(\hat{C}_{i,j}^{n+1} + \frac{\Delta t}{2} I_{i,j}\right) \qquad (39)$$

$$K_{i,j} = S_{i,j}\left(\hat{C}_{i,j}^{n+1} + \Delta t\, J_{i,j}\right) \qquad (40)$$

Where: $S_{i,j}(C_{i,j})$ = Net loading and kinetic reaction term for water quality constituent *j* at model node *i* given the concentration of the constituents specified by the array $C_{i,j}$.

## Time Step Calculation

Because the MacCormack Predictor – Corrector method is explicit, the size of the time step controls the stability of the advective – dispersion calculations. To a lesser extent, this is also true for the simulation of the net loading and kinetic reaction terms. Unfortunately, a simple stability criterion for the MacCormack algorithm does not exist when the method is applied to the advection – dispersion equation. However, *TAMDL* uses the minimum of three criteria suggested by Anderson, Tannehill and Pletcher (1984). Because the mean stream velocity, $V$, may change each time step, the inequality (41) is evaluated at the beginning of each time step.

$$\Delta t \le \min\left(\frac{(\Delta x)^2}{2m}, \frac{\Delta x}{|V|}, \frac{(\Delta x)^2}{2m + |V|\Delta x}\right) \tag{41}$$

In order to give the user full control over the simulation, the user can specify a maximum time step for the program to use. However, the quality of the simulation can be degraded if a time step much smaller than that specified by inequality (41) is employed. Like the MacCormack method, no simple stability criterion for the Runge-Kutta method exists. However, *TAMDL* uses the following heuristic formula to ensure that it does not calculate negative concentrations of ferrous iron, ferric iron, manganese, total aluminum or dissolved oxygen.

$$\Delta t \le \min\left(-\frac{C_{i,j}^n}{\max(S_{i,j}(C_{i,j}^n), 0)}\right) \forall i, j \text{ where } j = 4, 5, 6, 7 \text{ or } 8 \tag{42}$$

Because this maximum allowable time step is a function of the concentrations of some of the water quality constituents, inequality (42) is also evaluated each time step. Inequality (42) is not evaluated for temperature or net acidity because negative values of these quantities do not automatically invalidate the results of the simulation.

## Conclusion

The computer program *TAMDL* is a powerful tool in simulating the one dimensional water quality of streams affected by acidic mine drainage and by the remediation of acidic mine drainage. This computer program simulates the transport and reaction of temperature, net acidity, pH, ferrous iron, ferric iron, manganese, aluminum and dissolved oxygen. With the exception of pH, the one dimensional advection – dispersion – loading – reaction partial differential equation is solved for these constituents. The pH is simulated with an empirical net acidity – pH relationship.

The advection terms in the governing equation involve the mean flow velocity, which is iteratively calculated with Manning's equation. Because the selected numerical algorithm requires that the velocity be constant throughout the model domain, the watershed is divided into several sub-watersheds of nearly constant hydrologic properties.

The contribution of the advection – dispersion terms in the governing equation are solved with the explicit MacCormack Predictor – Corrector finite difference method. Whereas the contribution of the loading – reaction terms are calculated with the fourth order Runge – Kutta method. Because the size of the time step is important for the stability of both of these algorithms, the time step size is calculated at the beginning of each time step.

**Formal List of *TAMDL* Modeling Assumptions**

1. *TAMDL* assumes that the transport, reaction and loading is governed by the one dimensional partial differential equation given in equation (1).

2. The program assumes that the magnitude of the hydrodynamic dispersion for all of the simulated water quality constituents, except for proton concentration (pH), is the same.

3. The program assumes that the water quality of streams affected by acidic mine drainage are controlled by the temperature, net acidity, pH and the concentration of ferrous iron, ferric iron, manganese, total aluminum and dissolved oxygen.

4. The program assumes that the stream pH is adequately simulated by the empirical net acidity – pH relationship presented in equation (2).

5. The program assumes that all of the ferrous iron that is oxidizes immediately forms ferric hydroxide as shown in chemical reaction (3).

6. The program assumes that the oxidation of ferrous iron is irreversible.

7. The program assumes that the sedimentation of ferric iron is controlled by the settling of stream sediment.

8. The program assumes that the settling of stream sediment is controlled by Stokes law.

9. The program assumes that the size distribution of stream sediment is adequately represented by the mean sediment size.

10. The program assumes that the specific density of the stream sediment is equal to 2.5.

11. The program assumes that settled ferric iron sediment cannot be re-suspended by the stream.

12. The program assumes that the oxidation and precipitation of manganese is irreversible.

13. The program assumes that the precipitation of aluminum is irreversible.

14. The program assumes that the stream discharge may be considered uniform within a particular sub-watershed.

15. The program assumes that the hydraulics of the stream can be characterized by a mean values for the manning roughness coefficient, bottom slope, bottom width, side slope, channel height and flood plain width, within a particular sub-watershed.

16. The program assumes that the hydraulics of the stream are nearly uniform, i.e. can be approximated with a uniform flow equation, and can be adequately modeled with Manning's equation.

17. The program assumes that the magnitude of time step appropriate for simulating the in-stream chemical and physical processes is comparable to the magnitude of time step appropriate for simulating the transport of the modeled water quality constituents.

## References


Anderson, D.A., J.C. Tannehill, R.H. Pletcher, *Computational Fluid Mechanics and Heat Transfer*, 1984, Hemisphere Publishing Company, New York, NY.

Boyce, W.E., and DiPrima, R.C., *Elementary Differential Equations and Boundary Value Problems*, Third Edition, 1977, John Wiley & Sons, Inc., New York, NY.

Cole, T.M., and Buchak, E.M. (1995). "CE-QUAL-W2: A two-dimensional, laterally averaged, Hydrodynamic and Water Quality Model, Version 2.0," *Draft Instruction Report*, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

C.S. Kirby, H.M. Thomas, G. Southam and R. Donald, "Relative Contributions of Abiotic and Biological Factors in Fe(II) Oxidation in Mine Drainage," *Applied Geochemistry*, preprint, 1998.

Henderson, F.M., *Open Channel Flow*, 1966, The Macmillan Company, New York, NY.

O'Conner, D.J. and W.E. Dobbins, "Mechanism of Reaeration in Natural Streams," *Transactions ASCE*, Volume 123, Number 655, 1958.

Roberson, J.A., C.T. Crowe, *Engineering Fluid Mechanics*, Second Edition, 1980, Houghton Mifflin Company, Boston, MA.

Stumm, W., J.J. Morgan, *Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters*, Second Edition, 1981, John Wiley and Sons, Inc., New York, NY.

Tchobanoglous, G., *Wastewater Engineering: Treatment Disposal and Reuse*, Third Edition, 1991, Metcalf and Eddy, Inc., McGraw-Hill Inc., New York, NY.

Ziemkiewicz, P.F., *Personal Communication*, 1999-2000.

**Table C5. List of stream segments requiring reduction in AMD sources according to base conditions model.**

| Sub-WS | Listed for pH? | Reduction required in acidity? | Listed for iron? | Reduction required in iron? | Listed for Mn? | Reduction required in Mn? | Listed for Al? | Reduction required in Al? | Sub-WS | Not listed but requiring reduction in acidity? | Not listed but requiring reduction in iron? | Not listed but requiring reduction in Mn? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | No | No | No | No | No | No | Yes | Yes | 1 | No | No | No |
| 2 | No | No | No | No | No | No | No | Yes | 2 | No | No | No |
| 3 | No | No | No | No | No | No | Yes | Yes | 3 | No | No | No |
| 4 | No | Yes | No | No | No | No | No | Yes | 4 | Yes | No | No |
| 5 | No | No | No | No | No | No | Yes | Yes | 5 | No | No | No |
| 6 | No | Yes | No | No | No | No | No | Yes | 6 | Yes | No | No |
| 7 | No | No | No | No | No | No | Yes | Yes | 7 | No | No | No |
| 8 | No | Yes | No | No | No | No | No | Yes | 8 | Yes | No | No |
| 9 | Yes | No | No | No | No | No | Yes | Yes | 9 | No | No | No |
| 10 | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | 10 | No | No | No |
| 11 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | 11 | No | No | No |
| 12 | No | Yes | No | Yes | No | Yes | No | Yes | 12 | Yes | Yes | Yes |
| 13 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | 13 | No | No | No |
| 14 | Yes | No | No | Yes | No | No | Yes | Yes | 14 | No | Yes | No |
| 15 | No | Yes | No | Yes | No | Yes | No | Yes | 15 | Yes | Yes | Yes |
| 16 | Yes | No | No | Yes | No | No | Yes | Yes | 16 | No | Yes | No |
| 17 | No | Yes | No | No | No | No | No | Yes | 17 | Yes | No | No |
| 18 | Yes | No | No | Yes | No | No | Yes | Yes | 18 | No | Yes | No |
| 19 | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | 19 | No | No | No |
| 20 | Yes | No | No | Yes | No | No | Yes | Yes | 20 | No | Yes | No |
| 21 | Yes | Yes | No | Yes | No | Yes | No | Yes | 21 | No | Yes | Yes |
| 22 | Yes | No | No | Yes | No | No | Yes | Yes | 22 | No | Yes | No |
| 23 | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | 23 | Yes | No | No |
| 24 | No | No | No | Yes | No | No | No | Yes | 24 | No | Yes | No |
| 25 | Yes | Yes | No | No | No | Yes | No | Yes | 25 | No | No | Yes |
| 26 | No | No | No | Yes | No | No | No | Yes | 26 | No | Yes | No |
| 27 | No | No | Yes | Yes | Yes | Yes | Yes | Yes | 27 | No | No | No |
| 28 | No | No | No | Yes | No | No | No | Yes | 28 | No | Yes | No |
| 29 | No | No | No | No | No | No | No | No | 29 | No | No | No |
| 30 | No | No | No | Yes | No | No | No | Yes | 30 | No | Yes | No |
| 31 | No | No | No | Yes | No | Yes | No | Yes | 31 | No | Yes | Yes |

**Table C5. List of stream segments requiring reduction in AMD sources according to base conditions model.**

| Sub-WS | Listed for pH? | Reduction required in acidity? | Listed for iron? | Reduction required in iron? | Listed for Mn? | Reduction required in Mn? | Listed for Al? | Reduction required in Al? | Sub-WS | Not listed but requiring reduction in acidity? | Not listed but requiring reduction in iron? | Not listed but requiring reduction in Mn? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | No | No | No | Yes | No | No | No | Yes | 32 | No | Yes | No |
| 33 | Yes | Yes | Yes | No | Yes | No | Yes | No | 33 | No | No | No |
| 34 | No | No | No | Yes | No | No | No | Yes | 34 | No | Yes | No |
| 35 | No | Yes | No | No | No | No | No | Yes | 35 | Yes | No | No |
| 36 | No | No | No | Yes | No | No | No | Yes | 36 | No | Yes | No |
| 37 | No | No | No | Yes | No | Yes | No | Yes | 37 | No | Yes | Yes |
| 38 | No | No | No | No | No | No | No | Yes | 38 | No | No | No |
| 39 | No | No | No | Yes | No | Yes | No | Yes | 39 | No | Yes | Yes |
| 40 | No | No | No | Yes | No | No | No | Yes | 40 | No | Yes | No |
| 41 | No | No | No | Yes | No | No | No | No | 41 | No | Yes | No |
| 42 | No | No | No | Yes | No | No | No | Yes | 42 | No | Yes | No |
| 43 | No | Yes | No | Yes | No | No | No | Yes | 43 | Yes | Yes | No |
| 44 | No | No | No | Yes | No | No | No | Yes | 44 | No | Yes | No |
| 45 | No | No | No | Yes | No | Yes | No | Yes | 45 | No | Yes | Yes |
| 46 | No | No | No | Yes | No | No | No | Yes | 46 | No | Yes | No |
| 47 | No | No | Yes | Yes | Yes | No | Yes | Yes | 47 | No | No | No |
| 48 | No | No | No | Yes | No | Yes | No | Yes | 48 | No | Yes | Yes |
| 49 | No | No | No | Yes | No | Yes | No | Yes | 49 | No | Yes | Yes |
| 50 | No | No | No | Yes | No | Yes | No | Yes | 50 | No | Yes | Yes |
| 51 | No | No | No | Yes | No | Yes | No | Yes | 51 | No | Yes | Yes |
| 52 | No | No | No | Yes | No | Yes | No | Yes | 52 | No | Yes | Yes |
| 53 | No | Yes | No | Yes | No | Yes | No | Yes | 53 | Yes | Yes | Yes |
| 54 | No | No | No | Yes | No | Yes | No | Yes | 54 | No | Yes | Yes |
| 55 | No | No | No | Yes | No | Yes | No | Yes | 55 | No | Yes | Yes |
| 56 | No | No | No | Yes | No | No | No | Yes | 56 | No | Yes | No |
| 57 | No | No | No | Yes | No | Yes | No | Yes | 57 | No | Yes | Yes |
| 58 | No | No | No | Yes | No | No | No | Yes | 58 | No | Yes | No |
| 59 | No | No | No | Yes | No | No | No | Yes | 59 | No | Yes | No |
| 60 | No | No | No | Yes | No | No | No | Yes | 60 | No | Yes | No |
| 61 | No | No | No | Yes | No | No | No | Yes | 61 | No | Yes | No |
| 62 | No | No | No | Yes | No | No | No | Yes | 62 | No | Yes | No |

**Table C5. List of stream segments requiring reduction in AMD sources according to base conditions model.**

| Sub-WS | Listed for pH? | Reduction required in acidity? | Listed for iron? | Reduction required in iron? | Listed for Mn? | Reduction required in Mn? | Listed for Al? | Reduction required in Al? | Sub-WS | Not listed but requiring reduction in acidity? | Not listed but requiring reduction in iron? | Not listed but requiring reduction in Mn? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| overall | 21% | 27% | 13% | 73% | 13% | 37% | 29% | 95% | overall | 16% | 65% | 27% |

| Not listed but requiring reduction in AI? |
|---|
| No |
| Yes |
| No |
| Yes |
| No |
| Yes |
| No |
| Yes |
| No |
| No |
| No |
| Yes |
| No |
| No |
| Yes |
| No |
| Yes |
| No |
| No |
| No |
| Yes |
| No |
| No |
| Yes |
| Yes |
| Yes |
| No |
| Yes |
| No |
| Yes |
| Yes |

| Not listed but requiring reduction in AI? |
|---|
| Yes |
| No |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| No |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| No |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |
| Yes |

| Not listed but requiring reduction in AI? |
|---|
| 68% |

## Appendix D: Results of the Paint Creek TAMDL Model

Because many of the Paint Creek sub-watersheds had little calibration data, this appendix will concentrate on those relatively few sub-watersheds from which most of the water quality samples were collected. Figures D1, D2, D3 and D4 are time series plots for WVDEP-SRG sample collection station PC054 where most of the Long Branch samples were collected. With a few exceptions, the observed readings appear to be matched by the model. The Long Branch and Ten Mile Fork sub-watersheds were, by far, the most difficult Paint Creek sub-watersheds to calibrate because of the action of the limestone sand treatment facilities installed by WVDEP-AML.

Figures D5, D6, D7 and D8 are time series plots for WVDEP-SRG sample collection station PC060, which is located near the center of the lower Ten Mile Fork sub-watershed. The sudden drop in simulated pH shown by Figure D5 is the result of a very low average pH reading reported by one of the mines in the sub-watershed. The increase in pH during water year 1998 is the result of the installation of the limestone sand treatment facilities upstream of the sample collection station. Additional calibration data would have permitted a better delineation of the decrease in acidity.

Figures D9, D10, D11 and D12 are time series plots for WVDEP-SRG sample collection station PC073, which is located near the mouth of Cedar Creek. Along with Ten Mile Fork and Long Branch, Cedar Creek is responsible for a major part of the watershed's discharge from abandoned mines. The observed readings show a significant increase in acidity and metals loading during water year 1999. Without additional calibration and AML seep data for this sub-watershed it is impossible to determine precisely the cause of the decline in water quality.

Table D1 and D2 contain the basic model parameters for each of the model's sub-watersheds. Excluded from the list are the nodal sources required for model calibration. The bottom channel width and Manning's roughness coefficient for each sub-watershed were calculated using the Manning equation from the flow area and wetted perimeter observed by WVDEP-SRG. WVDEP-SRG personal measured stream flow along with collecting water quality samples under high, medium and low flow conditions.

While some of the assigned values for the Manning's roughness coefficient may greater than the design values given in Table 5-6 of (Chow, V.T. *Open Channel Hydraulics* 1959, McGraw-Hill Book Company, Inc., New York, NY), the values given by Chow (1959) were intended to be used with the Manning equation for reasonably straight channels with uniform or gradually varied flow. The Paint Creek tributaries are generally not straight and have a wide variation in both channel slope and cross sectional dimensions. Because TAMDL is simulating the hydraulics of non-prismatic channels under gradually or rapidly varied flow conditions with the Manning uniform flow equation, the presence of some unusually high values for Manning's n is not unexpected. This result could have been avoided, if there was enough detailed hydraulic and geometric stream data to warrant the use of a more sophisticated hydraulic model.

Experimental TAMDL simulations were also executed to ensure that these values yielded reasonable results with the stream bottom slopes obtained from the DEM in WCMS. Only the hydraulic parameters for Cedar Creek, sub-watershed #21, required adjustment to obtain reasonable results. These adjustments were necessary given that the original hydraulic parameters yielded depths less than 5 cm during low flow conditions. Extremely shallow depths can cause numerical instabilities during TAMDL simulations because the rates of some of the modeled physical and chemical processes are inversely proportional to the hydraulic depth.

Non-point source loading for calibration and baseline models.

The upstream boundary conditions for the downstream sub-watersheds are defined by the model results calculated for those sub-watersheds immediately upstream. Sub-watersheds that have no other sub-watersheds above them, tributary sub-watersheds, have upstream boundary conditions defined by an upstream concentration. The total load entering a tributary sub-watershed is the sum of the upstream concentration multiplied by the stream's discharge and the loads entering the sub-watershed's model nodes.

In the Paint Creek TAMDL models, non-point sources can be divided into three classes: a source with a constant loading rate throughout the simulation, a source with a loading rate that varies during the simulation, or a source with a constant loading rate that is started during the simulation period. Seeps that drain abandoned underground mines were assumed to have a constant load throughout the simulation. Minor streams that entered the sub-watershed's stream segment were assigned a loading rate that varied during the simulation. In-stream AMD treatment facilities that were installed during the simulation period were assigned a constant alkaline (negative net acidic) loading rate that started when the facility was installed. The Paint Creek TAMDL model uses a datum date and time of 2400 hours, 31 December 1989.

Point sources entering the calibration model.

These loads were calculated from the reported monthly average concentrations and flow rates reported by the mine operators on the DMR submitted to WVDEP. All of the known DMR data was used to estimate the monthly mean flow rate for all of the currently discharging mine outlets. Because it is quite common for mine outlets to be permitted well in advance of the time the outlet begins to release mine drainage, only reported DMR data were included in the calibration model's point sources. This approach is vulnerable to errors caused by incomplete DMR records, but it is the most accurate representation of reality.

Point sources for the models.

The point sources for the baseline conditions model were calculated using the reported or estimated monthly mean flow rate for each outlet. Upstream concentrations for the tributary sub-watersheds in the allocation model were reduced during the load allocation. The non-point model node sources for the allocation model. Like the concentrations in Table D7, the loads in Table D8 were reduced during the load allocation.

The wasteload allocation was conducted by lowering the effluent concentrations of the permitted mine outlets until the model results indicated that the TMDL endpoints were being maintained during the simulation. The reduced point source loading rates that resulted from the lowering of the effluent concentrations are listed in Table D9.

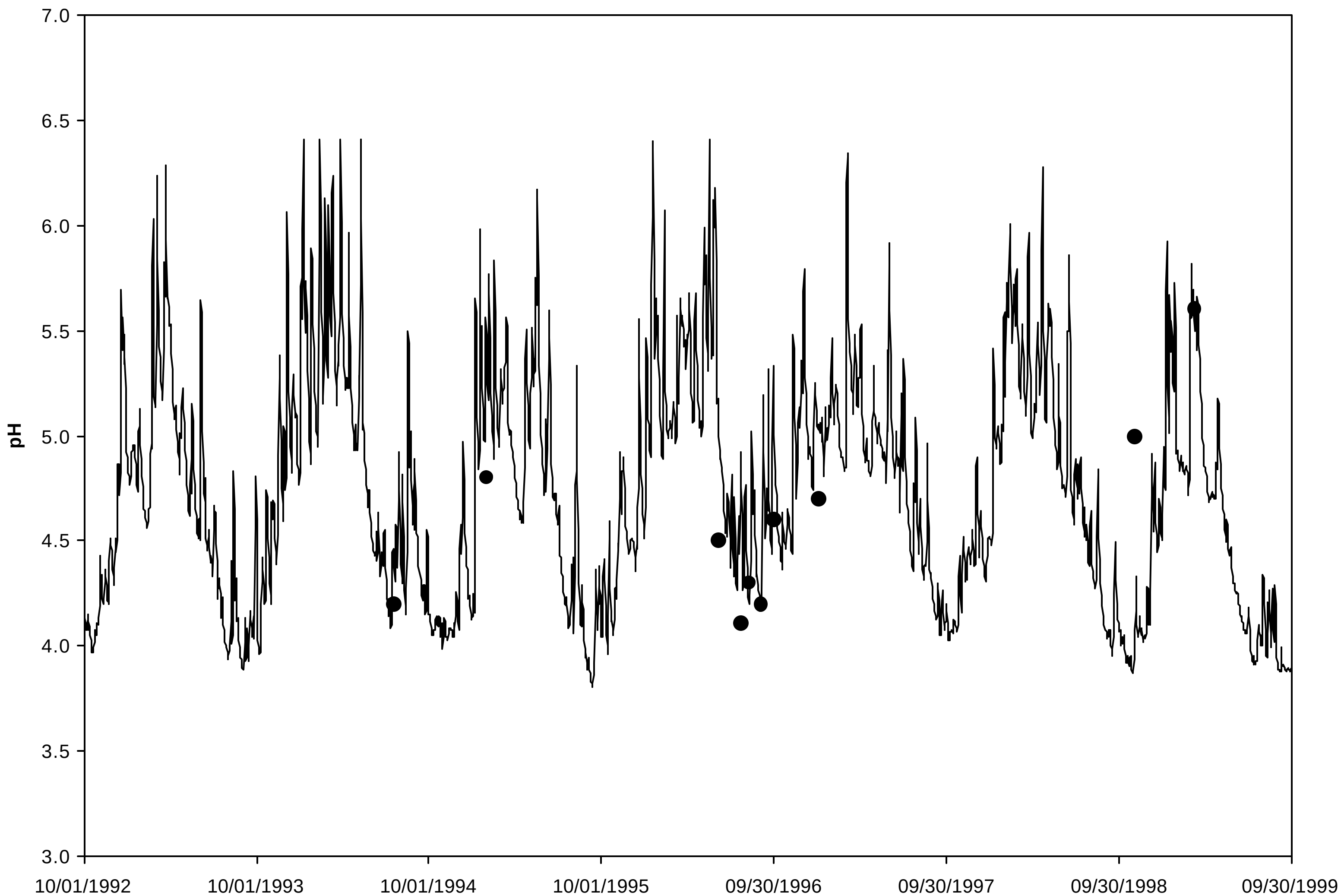



Figure D1. Time Series Plot of Observed and Calculated pH for WVDEP-SRG Station PC054.

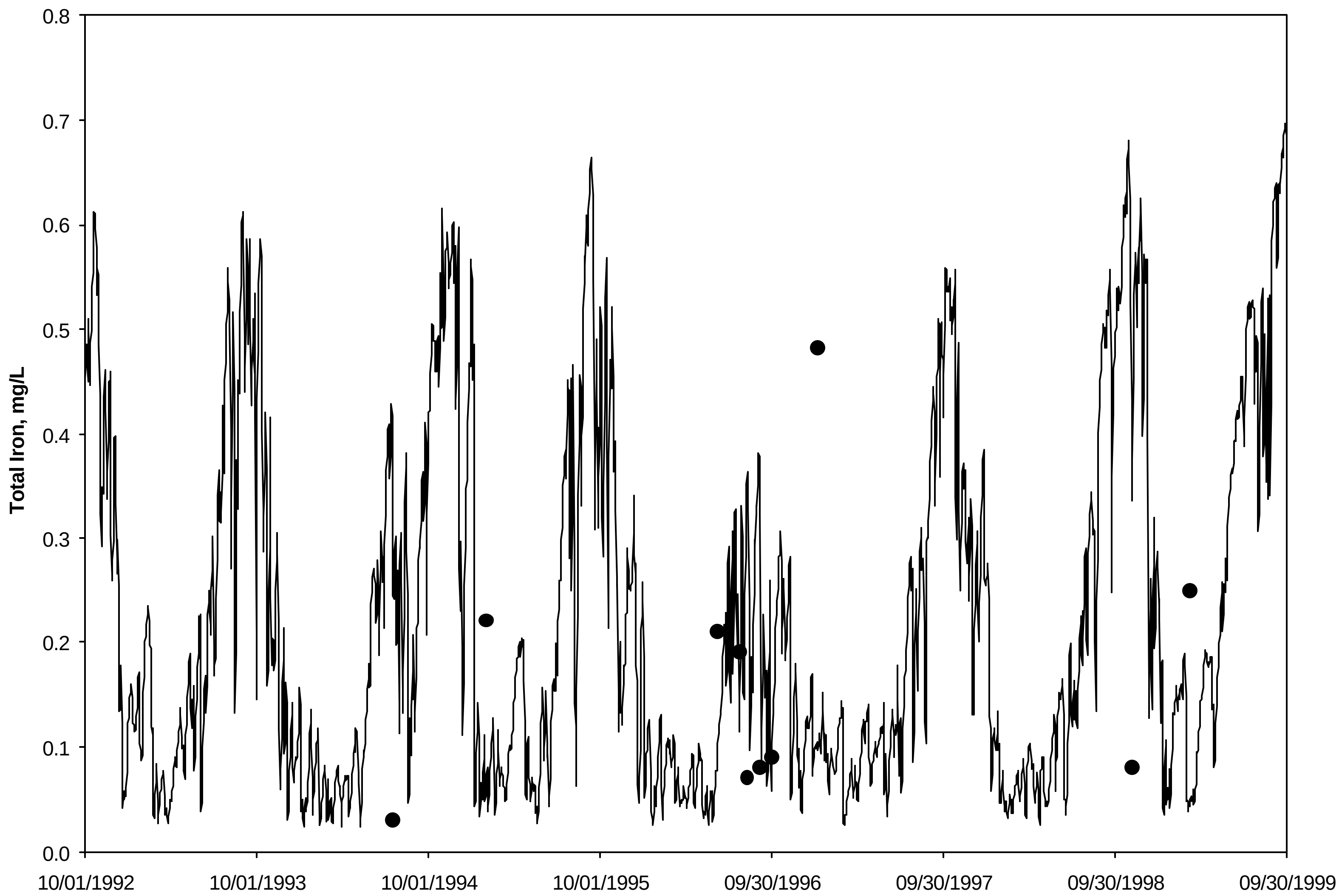



Figure D2. Time Series Plot of Observed and Calculated Total Iron for WVDEP-SRG Station PC054.

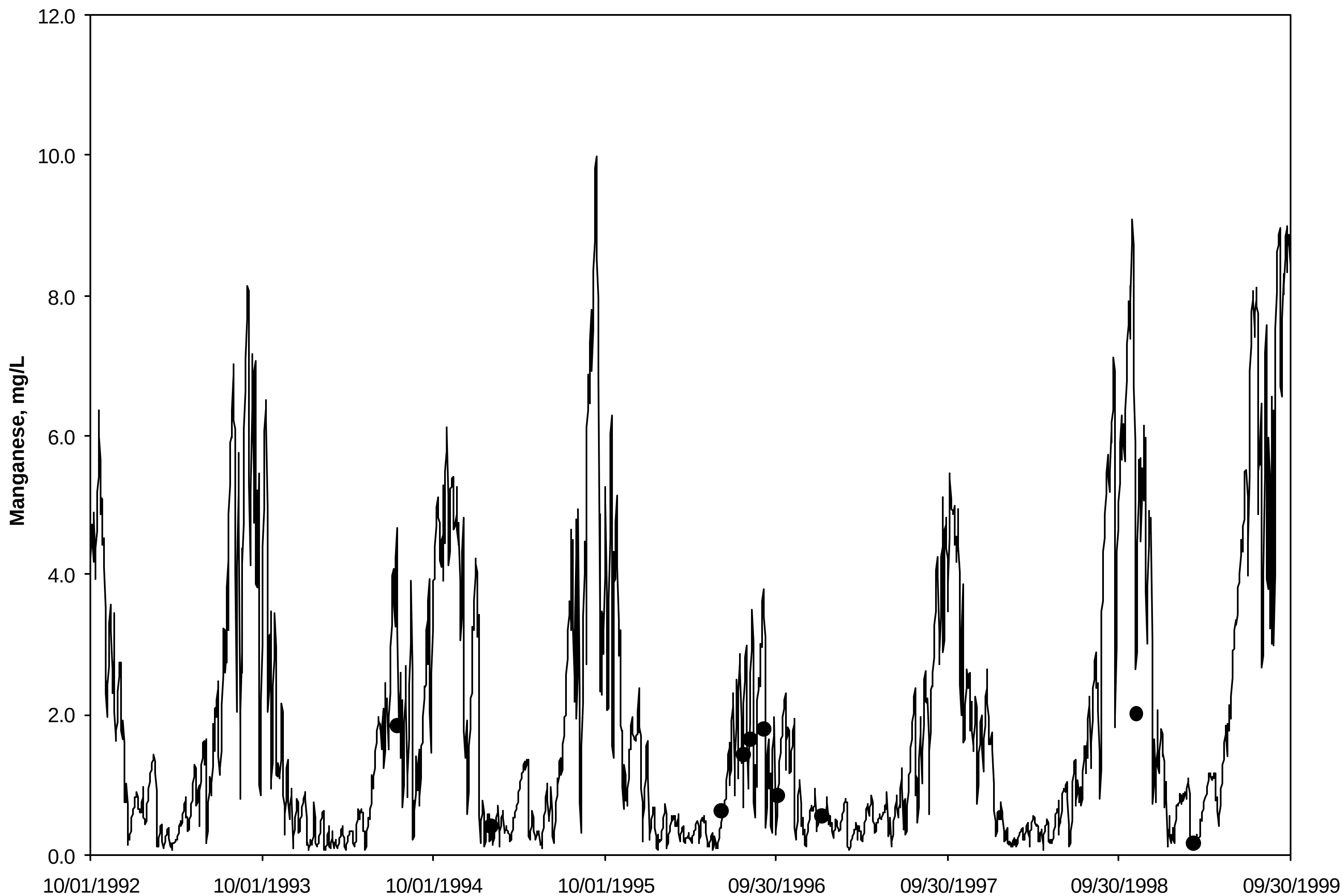



Figure D3. Time Series Plot of Observed and Calculated Manganese for WVDEP-SRG Station PC054.

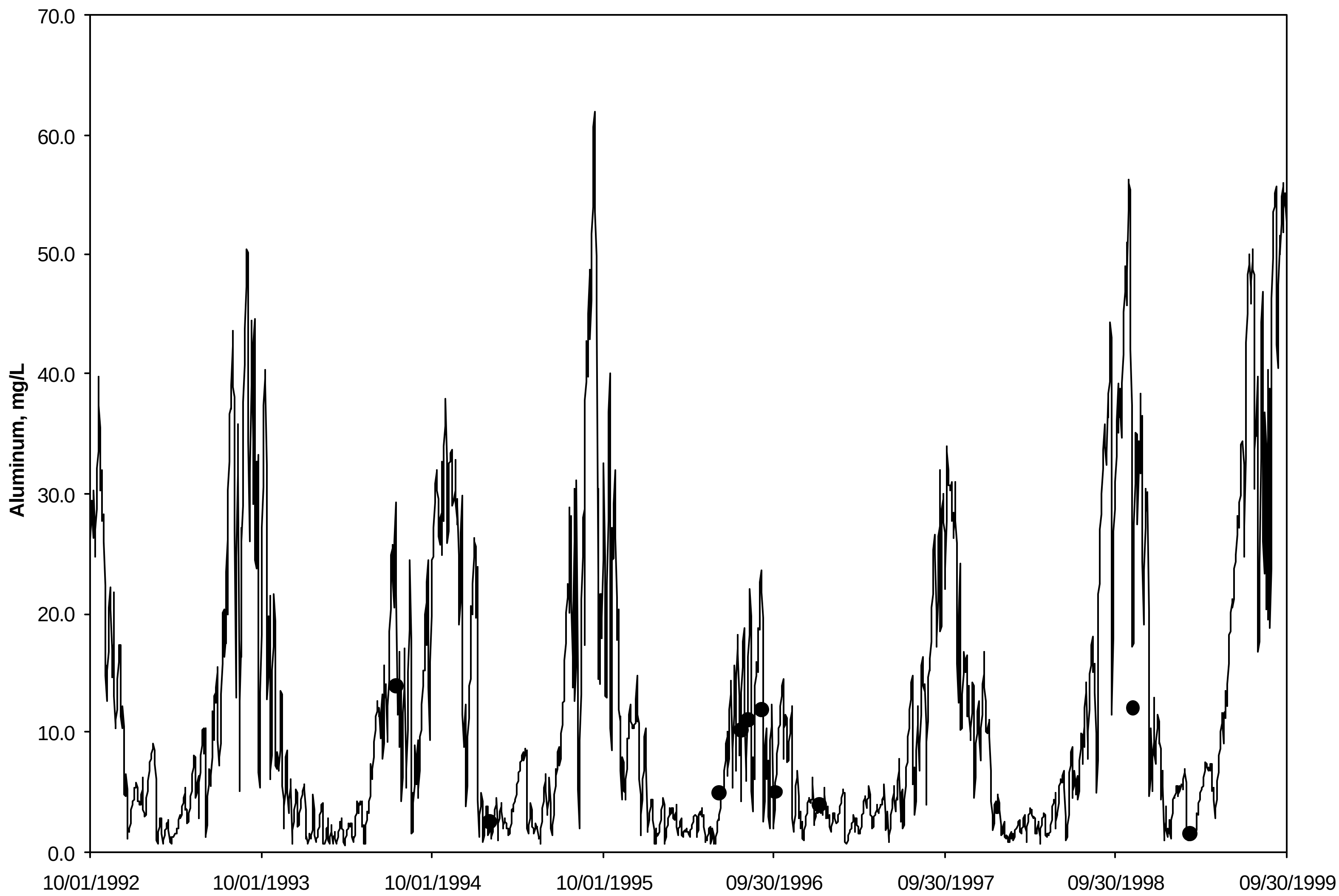



Figure D4. Time Series Plot of Observed and Calculated Aluminum for WVDEP-SRG Station PC054.

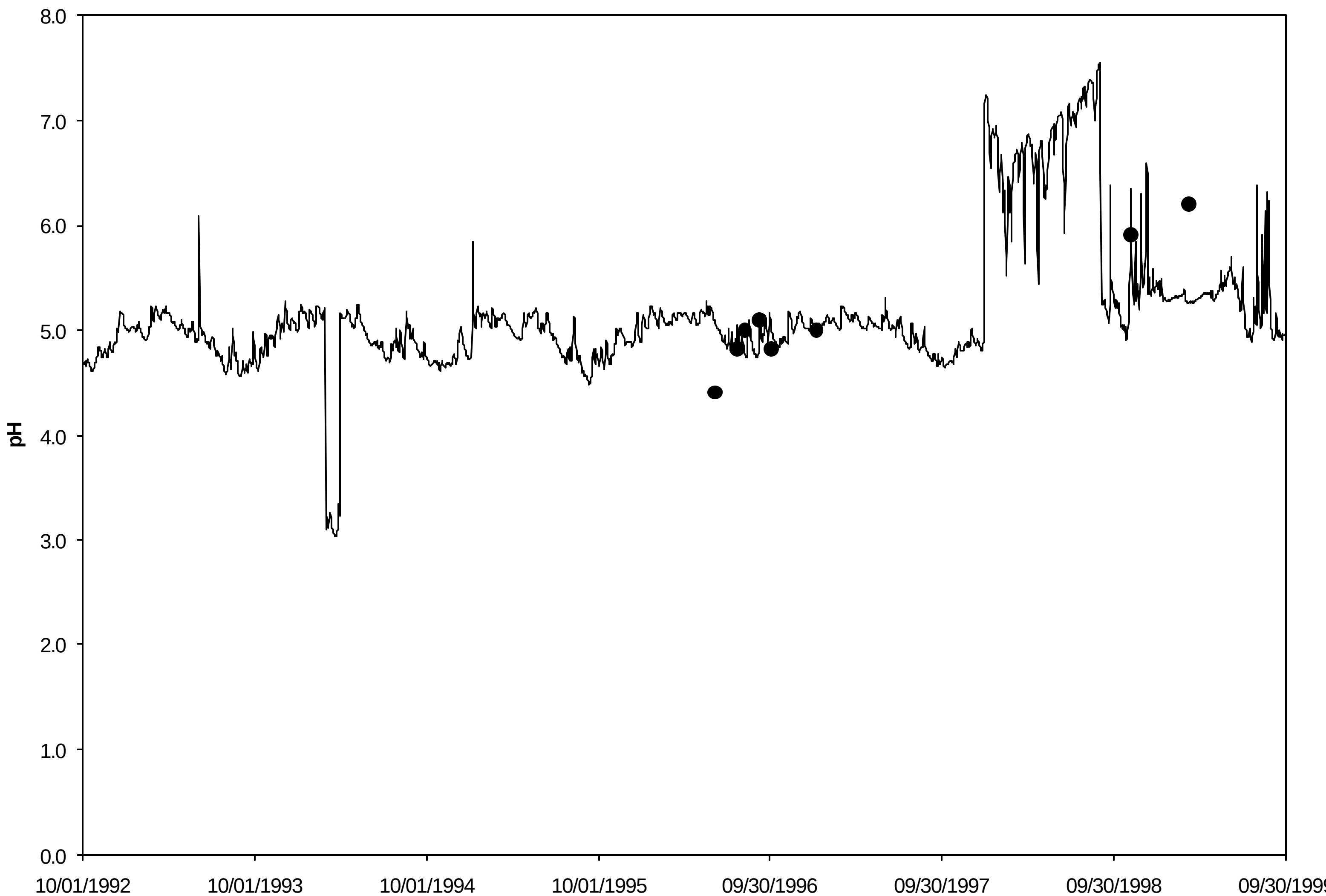



Figure D5. Time Series Plot of Observed and Calculated pH for WVDEP-SRG Station PC060.

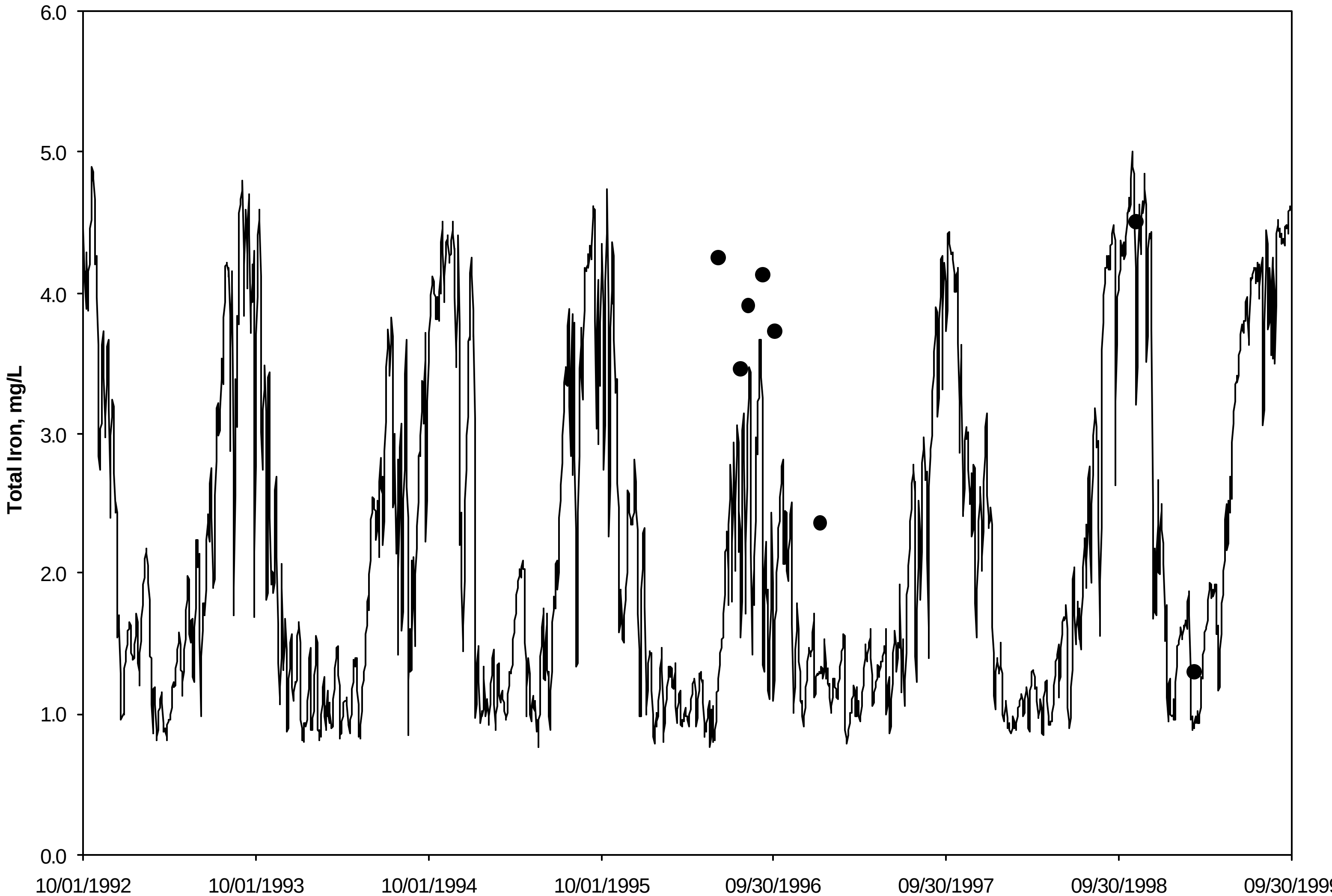



Figure D6. Time Series Plot of Observed and Calculated Total Iron for WVDEP-SRG Station PC060.

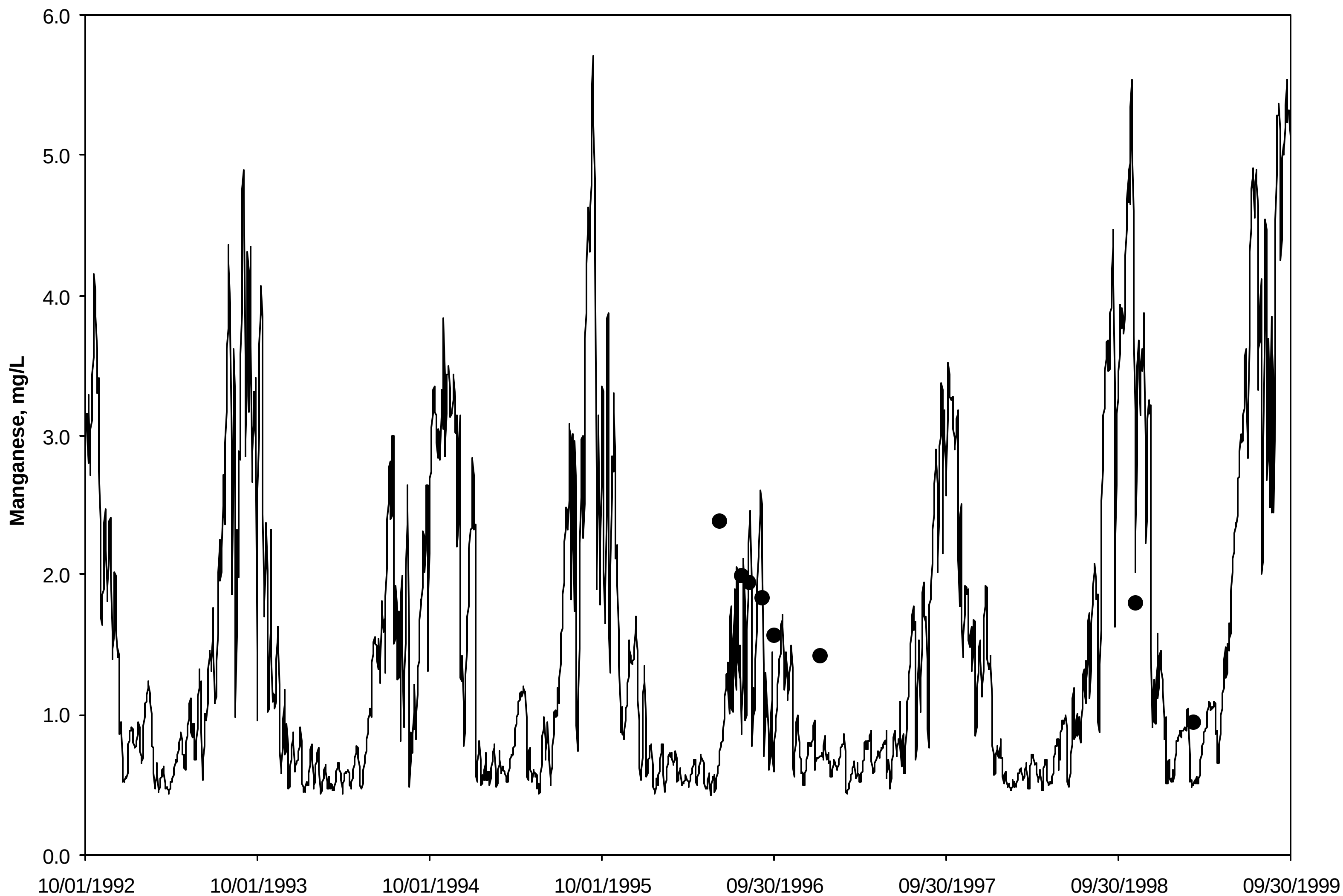



Figure D7. Time Series Plot of Observed and Calculated Manganese for WVDEP-SRG Station PC060.

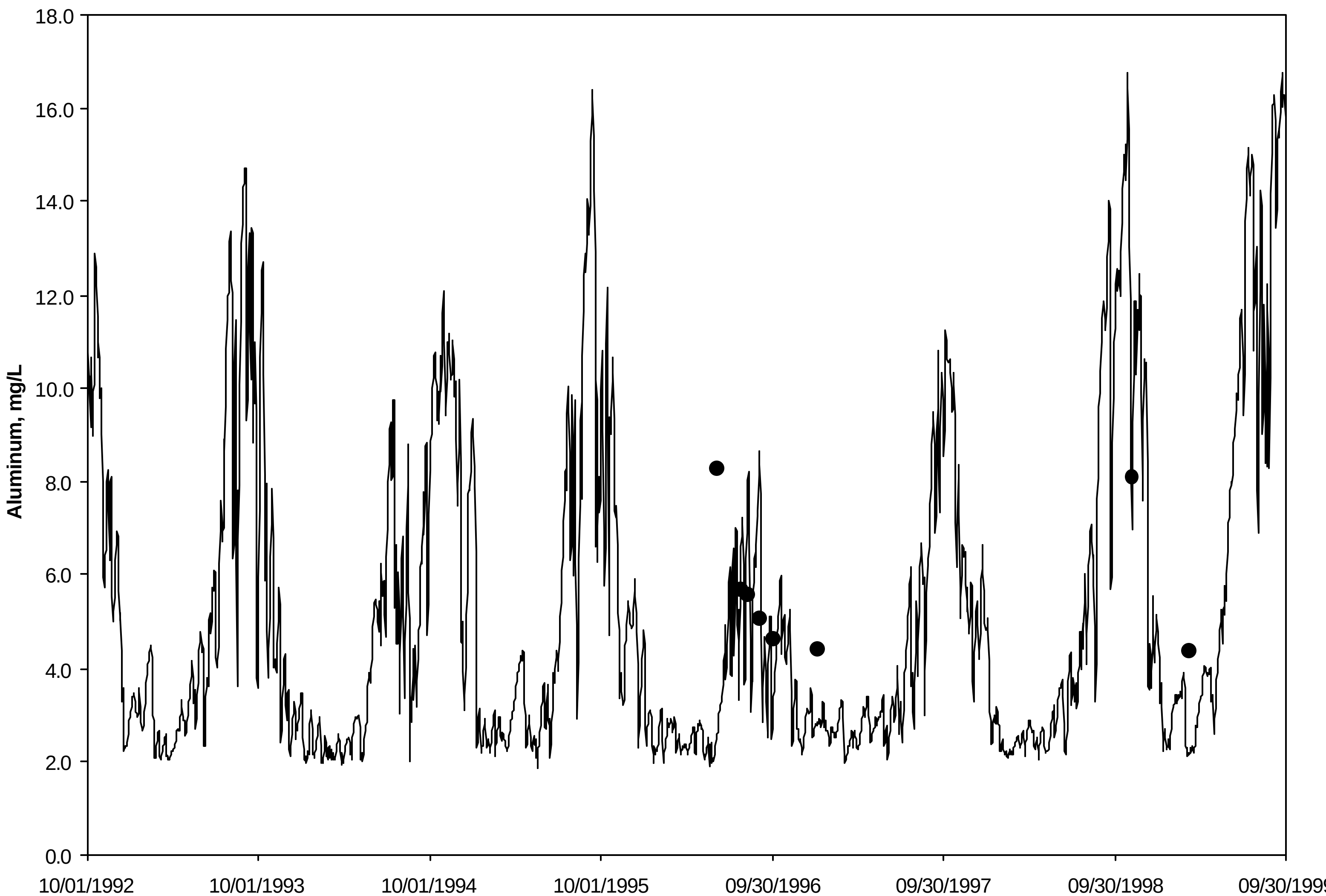



Figure D8. Time Series Plot of Observed and Calculated Total Aluminum for WVDEP-SRG Station PC060.

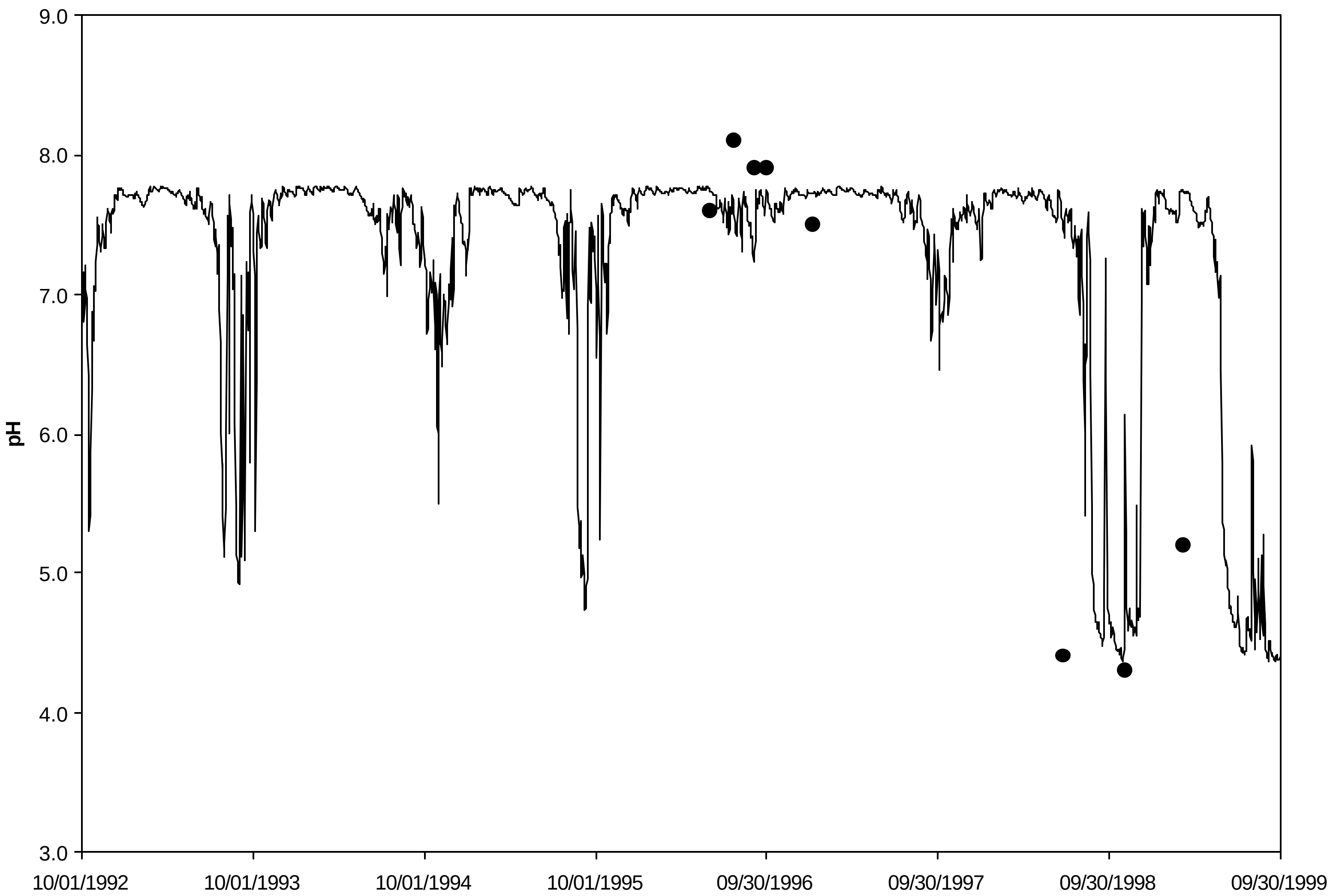



Figure D9. Time Series Plot of Observed and Calculated pH for WVDEP-SRG Station PC073.

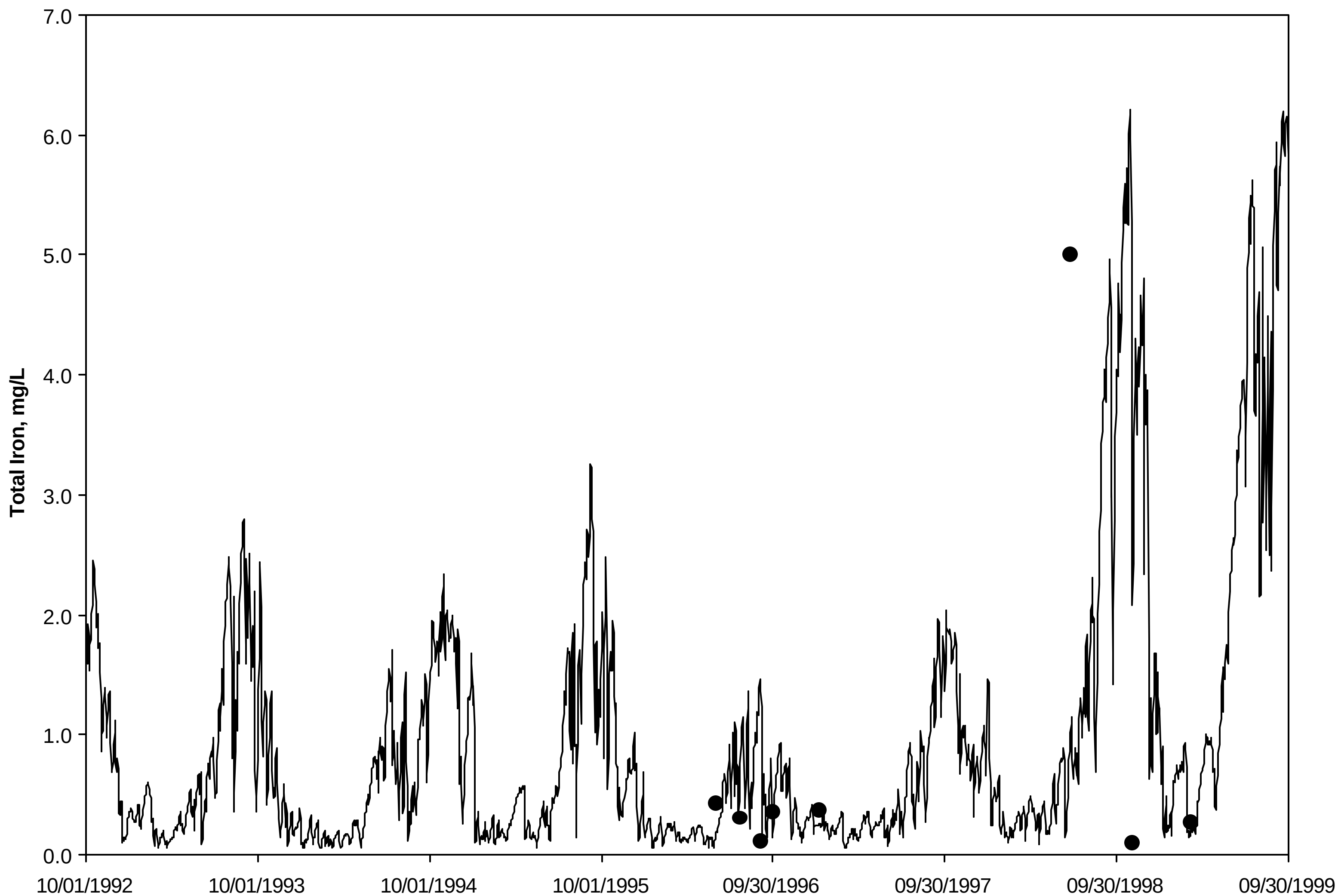



Figure D10. Time Series Plot of Observed and Calculated Total Iron for WVDEP-SRG Station PC073.

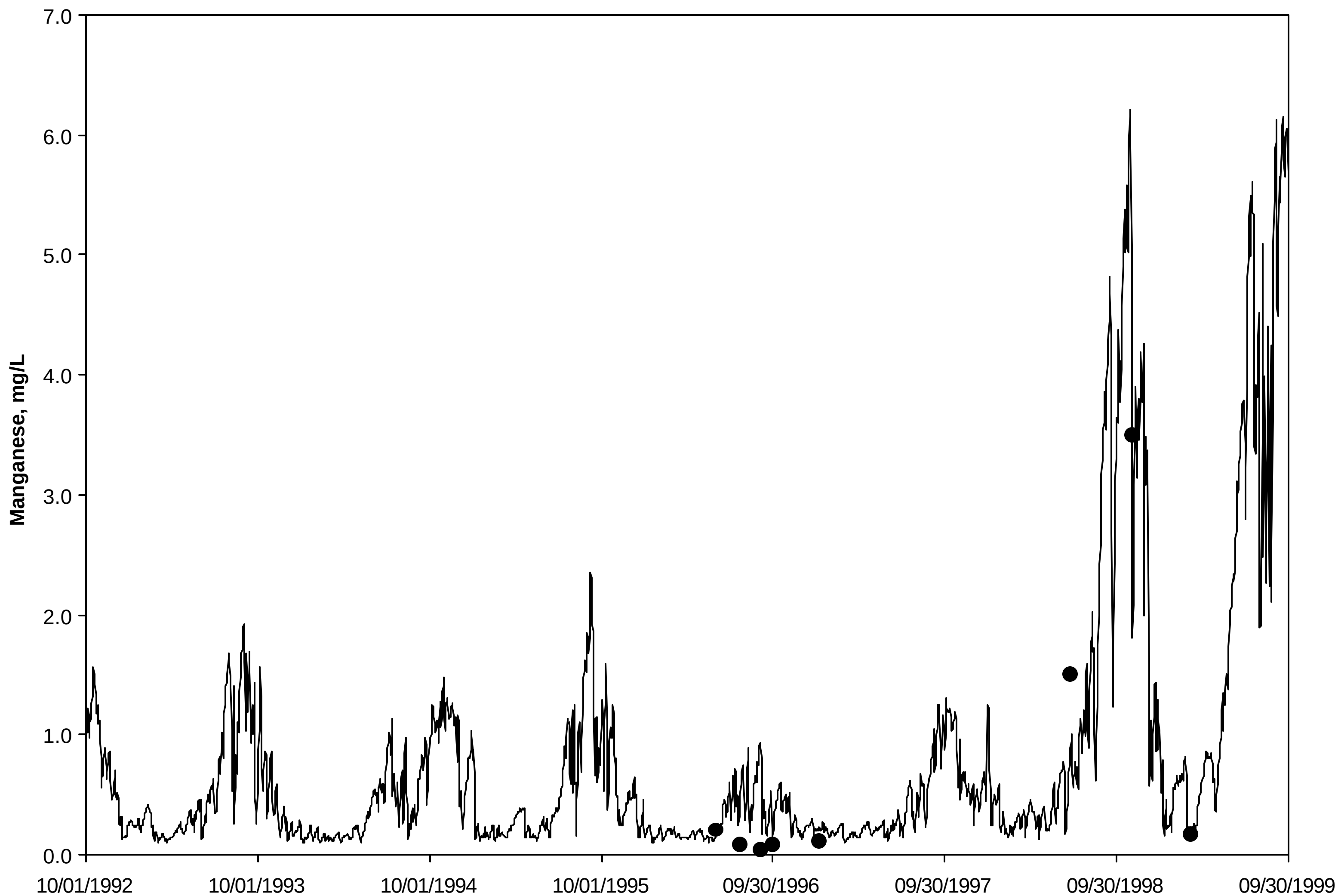



Figure D11. Time Series Plot of Observed and Calculated Manganese for WVDEP-SRG Station PC073.

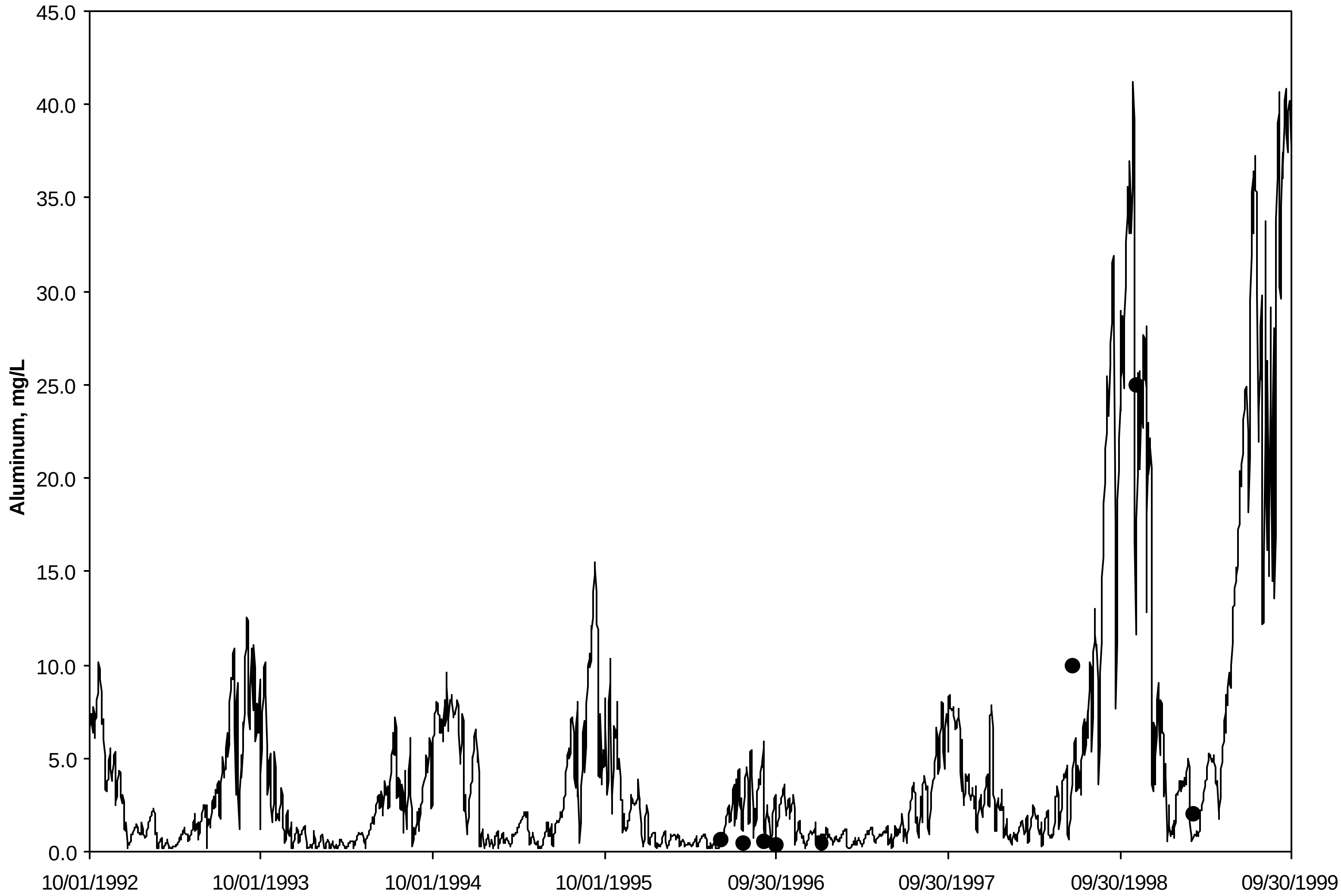



Figure D12. Time Series Plot of Observed and Calculated Aluminum for WVDEP-SRG Station PC073.

**Table D1. Finite Difference and Hydraulic Parameters for Paint Creek TAMDL Models.**

| SWS | Model Nodes | Node Spacing, m | Bottom Width, m | Inverse Side Slope | Mannings Roughness Coefficient | Channel Bottom Slope | Maximum Time Step, days |
|---|---|---|---|---|---|---|---|
| 1 | 39 | 201.20 | 8.82 | 2.00 | 0.030 | 0.002200 | 1.000 |
| 2 | 25 | 208.15 | 1.35 | 2.00 | 0.530 | 0.062200 | 0.010 |
| 3 | 8 | 216.56 | 8.82 | 2.00 | 0.030 | 0.002000 | 1.000 |
| 4 | 39 | 200.37 | 3.28 | 2.00 | 0.110 | 0.062200 | 0.010 |
| 5 | 26 | 206.85 | 4.08 | 2.00 | 0.030 | 0.002130 | 1.000 |
| 6 | 10 | 200.21 | 0.91 | 2.00 | 0.160 | 0.081820 | 1.000 |
| 7 | 18 | 202.28 | 4.08 | 2.00 | 0.030 | 0.004950 | 1.000 |
| 8 | 16 | 206.61 | 0.20 | 2.00 | 0.190 | 0.110000 | 1.000 |
| 9 | 17 | 204.21 | 4.08 | 2.00 | 0.030 | 0.005220 | 1.000 |
| 10 | 34 | 200.58 | 0.91 | 2.00 | 0.410 | 0.061300 | 1.000 |
| 11 | 5 | 241.38 | 1.18 | 2.00 | 0.160 | 0.037400 | 1.000 |
| 12 | 13 | 213.62 | 1.01 | 2.00 | 0.070 | 0.118000 | 1.000 |
| 13 | 15 | 213.21 | 1.01 | 2.00 | 0.070 | 0.109000 | 1.000 |
| 14 | 8 | 206.76 | 14.50 | 2.00 | 0.190 | 0.012400 | 1.000 |
| 15 | 10 | 216.27 | 0.84 | 2.00 | 0.410 | 0.153500 | 1.000 |
| 16 | 12 | 203.54 | 14.50 | 2.00 | 0.190 | 0.004910 | 1.000 |
| 17 | 8 | 218.00 | 0.28 | 2.00 | 0.981 | 0.268000 | 0.010 |
| 18 | 5 | 86.98 | 14.50 | 2.00 | 0.190 | 0.005750 | 1.000 |
| 19 | 12 | 217.90 | 0.55 | 2.00 | 0.710 | 0.186900 | 0.010 |
| 20 | 5 | 223.58 | 14.50 | 2.00 | 0.190 | 0.023500 | 1.000 |
| 21 | 10 | 219.17 | 0.30 | 0.00 | 1.000 | 0.172400 | 1.000 |
| 22 | 10 | 213.31 | 14.50 | 2.00 | 0.190 | 0.002080 | 1.000 |
| 23 | 17 | 206.42 | 2.31 | 2.00 | 0.180 | 0.122900 | 1.000 |
| 24 | 7 | 225.01 | 14.50 | 2.00 | 0.190 | 0.017000 | 1.000 |
| 25 | 11 | 217.83 | 0.73 | 2.00 | 0.829 | 0.140500 | 0.001 |
| 26 | 9 | 221.64 | 14.50 | 2.00 | 0.190 | 0.018100 | 1.000 |
| 27 | 12 | 216.88 | 1.08 | 2.00 | 0.160 | 0.153400 | 0.010 |
| 28 | 10 | 205.78 | 14.50 | 2.00 | 0.190 | 0.018400 | 1.000 |
| 29 | 14 | 206.33 | 0.36 | 2.00 | 0.180 | 0.090220 | 1.000 |
| 30 | 7 | 217.57 | 14.50 | 2.00 | 0.190 | 0.006130 | 1.000 |
| 31 | 25 | 205.57 | 0.90 | 2.00 | 0.180 | 0.068102 | 1.000 |
| 32 | 8 | 202.32 | 14.50 | 2.00 | 0.190 | 0.023300 | 1.000 |
| 33 | 10 | 203.76 | 2.22 | 2.00 | 0.120 | 0.056167 | 0.001 |
| 34 | 17 | 207.56 | 14.50 | 2.00 | 0.190 | 0.001810 | 1.000 |
| 35 | 16 | 211.89 | 1.38 | 2.00 | 0.440 | 0.092816 | 0.010 |
| 36 | 5 | 87.75 | 14.50 | 2.00 | 0.190 | 0.025600 | 1.000 |
| 37 | 19 | 210.21 | 0.42 | 2.00 | 0.040 | 0.005810 | 1.000 |
| 38 | 25 | 205.74 | 1.72 | 2.00 | 0.270 | 0.030378 | 1.000 |
| 39 | 38 | 201.26 | 1.03 | 2.00 | 1.380 | 0.017323 | 1.000 |
| 40 | 25 | 202.50 | 1.72 | 2.00 | 0.270 | 0.012600 | 1.000 |
| 41 | 13 | 208.27 | 0.90 | 2.00 | 0.160 | 0.014404 | 1.000 |
| 42 | 13 | 200.12 | 1.72 | 2.00 | 0.270 | 0.000416 | 1.000 |
| 43 | 18 | 203.54 | 0.93 | 2.00 | 0.350 | 0.031790 | 1.000 |
| 44 | 5 | 201.83 | 1.72 | 2.00 | 0.270 | 0.001240 | 1.000 |
| 45 | 20 | 205.83 | 0.61 | 2.00 | 0.210 | 0.084896 | 1.000 |
| 46 | 18 | 205.98 | 1.72 | 2.00 | 0.270 | 0.002000 | 1.000 |

**Table D1. Finite Difference and Hydraulic Parameters for Paint Creek TAMDL Models.**

| SWS | Model Nodes | Node Spacing, m | Bottom Width, m | Inverse Side Slope | Mannings Roughness Coefficient | Channel Bottom Slope | Maximum Time Step, days |
|---|---|---|---|---|---|---|---|
| 47 | 26 | 203.89 | 0.59 | 2.00 | 0.160 | 0.009809 | 1.000 |
| 48 | 21 | 209.39 | 1.72 | 2.00 | 0.270 | 0.001430 | 1.000 |
| 49 | 18 | 207.59 | 0.49 | 2.00 | 0.460 | 0.066873 | 1.000 |
| 50 | 10 | 200.21 | 1.72 | 2.00 | 0.270 | 0.010500 | 1.000 |
| 51 | 9 | 208.87 | 6.30 | 2.00 | 0.100 | 0.017400 | 1.000 |
| 52 | 5 | 243.98 | 4.24 | 2.00 | 0.290 | 0.017400 | 1.000 |
| 53 | 26 | 101.25 | 1.18 | 2.00 | 0.210 | 0.015013 | 1.000 |
| 54 | 32 | 206.24 | 0.46 | 2.00 | 0.260 | 0.028936 | 1.000 |
| 55 | 32 | 206.24 | 0.34 | 2.00 | 0.620 | 0.031268 | 1.000 |
| 56 | 5 | 152.49 | 3.08 | 2.00 | 0.330 | 0.004920 | 1.000 |
| 57 | 11 | 202.72 | 0.09 | 2.00 | 0.370 | 0.084846 | 1.000 |
| 58 | 13 | 200.79 | 3.08 | 2.00 | 0.330 | 0.009960 | 1.000 |
| 59 | 15 | 209.03 | 1.03 | 2.00 | 0.500 | 0.068684 | 0.010 |
| 60 | 8 | 226.45 | 3.08 | 2.00 | 0.330 | 0.001260 | 1.000 |
| 61 | 19 | 207.57 | 0.11 | 2.00 | 0.070 | 0.034793 | 1.000 |
| 62 | 20 | 200.45 | 0.08 | 2.00 | 0.003 | 0.027570 | 1.000 |

**Table D2. Water Quality Parameters for Paint Creek TAMDL Models.**

| SWS | Hydrodynamic Dispersion, m2/day | Mean Sediment Diameter, m | First Net Acidity - pH Constant, SU/(mg/L)2b | Second Net Acidity - pH Constant (b) | Empirical Aluminum Kinetic Coefficient | Empirical Manganese Kinetic Coefficient, 1/(mg/L)4/day |
|---|---|---|---|---|---|---|
| 1 | 1.0E+05 | 4.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 2 | 1.0E+03 | 1.0E-06 | 6.136517 | -0.027648 | 1.0E-18 | 1.0E+00 |
| 3 | 1.0E+00 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 4 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 5 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 6 | 1.0E+03 | 1.0E-06 | 6.485866 | -0.023431 | 1.0E-18 | 1.0E+00 |
| 7 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 8 | 1.0E+00 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 9 | 1.0E+05 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 10 | 9.0E+05 | 2.0E-06 | 6.414215 | -0.046430 | 1.0E-18 | 1.0E+00 |
| 11 | 1.0E+00 | 1.0E-06 | 5.844200 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 12 | 1.0E+03 | 1.0E-06 | 5.844246 | -0.030484 | 1.0E-18 | 1.0E+00 |
| 13 | 1.0E+04 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 14 | 1.0E+03 | 1.0E-05 | 6.350000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 15 | 1.0E+03 | 1.5E-06 | 5.400000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 16 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 17 | 1.0E+03 | 1.0E-06 | 5.478805 | -0.032232 | 1.0E-15 | 1.0E+00 |
| 18 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 19 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+04 |
| 20 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 21 | 1.0E+03 | 1.0E-06 | 6.006690 | -0.032960 | 1.0E-18 | 1.0E+00 |
| 22 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 23 | 1.0E+03 | 5.0E-06 | 5.327925 | -0.034780 | 1.0E-18 | 1.0E+00 |
| 24 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 25 | 1.0E+03 | 1.0E-06 | 5.000000 | -0.026332 | 1.0E-18 | 1.0E+00 |
| 26 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 27 | 1.0E+03 | 1.0E-06 | 5.283879 | -0.045928 | 1.0E-20 | 1.0E+00 |
| 28 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 29 | 1.0E+03 | 1.0E-06 | 5.000000 | -0.067674 | 1.0E-16 | 1.0E+00 |
| 30 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 31 | 1.0E+03 | 1.0E-06 | 5.000000 | -0.050846 | 1.0E-16 | 1.0E+00 |
| 32 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 33 | 1.0E+03 | 1.0E-06 | 6.700000 | -0.020000 | 1.0E-16 | 1.0E+00 |
| 34 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 35 | 1.0E+03 | 1.0E-06 | 5.508978 | -0.036358 | 1.0E-18 | 1.0E+00 |
| 36 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 37 | 5.0E+03 | 2.0E-06 | 5.540300 | -0.038241 | 1.0E-18 | 1.0E+00 |
| 38 | 1.0E+03 | 1.0E-06 | 5.023840 | -0.051921 | 1.0E-16 | 1.0E+00 |
| 39 | 1.0E+03 | 1.0E-06 | 5.754938 | -0.031614 | 1.0E-18 | 1.0E+00 |
| 40 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 41 | 1.0E+03 | 1.0E-06 | 6.626049 | -0.018438 | 1.0E-16 | 1.0E+00 |
| 42 | 1.0E+03 | 1.0E-06 | 6.300000 | -0.020000 | 1.0E-18 | 1.0E+00 |

**Table D2. Water Quality Parameters for Paint Creek TAMDL Models.**

| SWS | Hydrodynamic Dispersion, m2/day | Mean Sediment Diameter, m | First Net Acidity - pH Constant, SU/(mg/L)2b | Second Net Acidity - pH Constant (b) | Empirical Aluminum Kinetic Coefficient | Empirical Manganese Kinetic Coefficient, 1/(mg/L)4/day |
|---|---|---|---|---|---|---|
| 43 | 1.0E+03 | 1.0E-06 | 6.618670 | -0.006549 | 1.0E-18 | 1.0E+00 |
| 44 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 45 | 1.0E+03 | 1.0E-06 | 5.000000 | -0.047517 | 1.0E-18 | 1.0E+00 |
| 46 | 1.0E+03 | 1.0E-06 | 6.000000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 47 | 1.0E+03 | 1.0E-06 | 5.000000 | -0.049391 | 1.0E-18 | 1.0E+00 |
| 48 | 1.0E+03 | 1.0E-06 | 6.000000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 49 | 1.0E+03 | 1.0E-06 | 6.465914 | -0.009138 | 1.0E-15 | 1.0E+00 |
| 50 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+02 |
| 51 | 1.0E+03 | 5.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 52 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+00 |
| 53 | 1.0E+03 | 1.0E-06 | 6.401801 | -0.020721 | 1.0E-18 | 1.0E+00 |
| 54 | 1.0E+03 | 1.0E-06 | 6.000000 | -0.023832 | 1.0E-18 | 1.0E+00 |
| 55 | 1.0E+03 | 1.0E-06 | 6.000000 | -0.022572 | 1.0E-18 | 1.0E+02 |
| 56 | 1.0E+03 | 5.0E-06 | 5.895000 | -0.015000 | 1.0E-19 | 1.0E+00 |
| 57 | 1.0E+03 | 1.0E-06 | 7.000000 | -0.011045 | 1.0E-18 | 1.0E+02 |
| 58 | 1.0E+03 | 1.0E-06 | 6.500000 | -0.020000 | 1.0E-18 | 1.0E+02 |
| 59 | 1.0E+03 | 1.0E-06 | 7.000000 | -0.006399 | 1.0E-18 | 1.0E+02 |
| 60 | 1.0E+03 | 1.0E-06 | 6.138000 | -0.022615 | 1.0E-18 | 1.0E+00 |
| 61 | 1.0E+05 | 2.0E-06 | 6.703630 | -0.011238 | 1.0E-15 | 1.0E+04 |
| 62 | 1.0E+03 | 1.0E-06 | 6.138009 | -0.022615 | 1.0E-18 | 1.0E+00 |

| Surface Heat Transfer Coefficient, calories/K |
|---|
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-07 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-07 |
| 1.0E-07 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |

| Surface Heat Transfer Coefficient, calories/K |
|---:|
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |
| 1.0E-05 |

| Table D3. Upstream Concentrations for Tributary Sub-Watersheds in Calibration and Baseline Models. | | | | | |
|---|---|---|---|---|---|
| SWS | Net Acidity, mg/L CaCO3 equivalents | pH, SU | Iron, mg/L | Manganese, mg/L | Aluminum, mg/L |
| 2 | -10.66 | 6.99 | 0.08 | 0.03 | 0.39 |
| 4 | 26.71 | 5.70 | 0.13 | 0.71 | 1.83 |
| 6 | 4.09 | 6.07 | 0.14 | 0.00 | 0.50 |
| 8 | 0.00 | 6.50 | 0.09 | 0.01 | 0.57 |
| 10 | 0.00 | 6.41 | 0.02 | 0.03 | 0.38 |
| 12 | 30.00 | 4.75 | 0.00 | 0.25 | 0.30 |
| 13 | 0.00 | 6.50 | 2.60 | 1.00 | 6.00 |
| 15 | -2999.27 | 7.44 | 0.16 | 0.03 | 2.18 |
| 17 | -10.00 | 6.36 | 0.23 | 0.08 | 0.76 |
| 19 | 50.00 | 5.56 | 0.13 | 1.00 | 5.66 |
| 21 | -50.00 | 7.77 | 0.05 | 0.10 | 0.10 |
| 23 | -15.90 | 6.46 | 6.00 | 4.45 | 7.15 |
| 25 | 24.25 | 4.23 | 0.13 | 0.00 | 0.00 |
| 27 | -15.50 | 6.80 | 0.24 | 0.16 | 0.95 |
| 29 | -20.00 | 7.50 | 0.33 | 0.14 | 0.43 |
| 31 | -36.00 | 7.20 | 0.26 | 0.24 | 1.05 |
| 33 | 0.00 | 6.70 | 0.07 | 0.03 | 0.55 |
| 35 | -9.38 | 6.48 | 0.21 | 0.00 | 0.60 |
| 38 | -14.88 | 6.65 | 0.16 | 0.01 | 0.53 |
| 39 | -11.93 | 6.73 | 1.27 | 0.07 | 0.57 |
| 41 | -1.59 | 6.74 | 0.13 | 0.06 | 0.17 |
| 43 | 15.44 | 6.39 | 0.05 | 0.04 | 0.30 |
| 45 | -47.46 | 7.22 | 0.29 | 0.23 | 1.55 |
| 47 | -28.47 | 6.96 | 0.06 | 0.02 | 0.28 |
| 49 | -4.67 | 6.65 | 0.00 | 0.00 | 0.26 |
| 53 | -0.24 | 6.40 | 0.08 | 0.00 | 0.31 |
| 54 | -21.29 | 6.94 | 0.04 | 0.06 | 0.54 |
| 55 | -16.53 | 6.81 | 0.60 | 0.37 | 0.55 |
| 57 | 9.62 | 6.66 | 0.00 | 0.00 | 0.10 |
| 59 | 5.16 | 6.85 | 0.06 | 0.01 | 0.16 |
| 61 | -12.50 | 7.10 | 0.26 | 0.03 | 0.24 |
| 62 | -20.17 | 7.03 | 0.05 | 0.01 | 0.40 |

**Table D4. Upstream Concentrations for Tributary Sub-Watersheds in Calibration and Baseline Models.**

| SWS | Net Acidity, mg/L CaCO3 equivalents | pH, SU | Iron, mg/L | Manganese, mg/L | Aluminum, mg/L |
|---|---|---|---|---|---|
| 2 | -10.66 | 6.99 | 0.08 | 0.03 | 0.20 |
| 4 | 0.00 | 6.50 | 0.13 | 0.71 | 0.70 |
| 6 | -5.00 | 6.99 | 0.14 | 0.00 | 0.25 |
| 8 | -10.00 | 7.13 | 0.09 | 0.01 | 0.04 |
| 10 | -1.50 | 6.66 | 0.02 | 0.03 | 0.10 |
| 12 | -30.00 | 7.19 | 0.00 | 0.16 | 0.15 |
| 13 | -10.00 | 7.13 | 0.36 | 0.20 | 0.10 |
| 15 | -2999.27 | 7.44 | 0.02 | 0.03 | 0.04 |
| 17 | -15.00 | 6.52 | 0.23 | 0.08 | 0.35 |
| 19 | 0.00 | 6.50 | 0.13 | 0.40 | 0.01 |
| 21 | -50.00 | 7.77 | 0.05 | 0.10 | 0.02 |
| 23 | -18.00 | 6.51 | 0.40 | 0.05 | 0.05 |
| 25 | -200.00 | 6.61 | 0.01 | 0.00 | 0.00 |
| 27 | -33.00 | 7.29 | 0.01 | 0.01 | 0.01 |
| 29 | -20.00 | 7.50 | 0.33 | 0.14 | 0.43 |
| 31 | -36.00 | 7.20 | 0.01 | 0.01 | 0.01 |
| 33 | 0.00 | 6.70 | 0.07 | 0.03 | 0.55 |
| 35 | -20.00 | 6.85 | 0.21 | 0.00 | 0.00 |
| 38 | -14.88 | 6.65 | 0.16 | 0.01 | 0.23 |
| 39 | -11.93 | 6.73 | 1.00 | 0.07 | 0.57 |
| 41 | -1.59 | 6.74 | 0.13 | 0.06 | 0.17 |
| 43 | 0.00 | 6.62 | 0.00 | 0.04 | 0.10 |
| 45 | -50.00 | 7.25 | 0.03 | 0.03 | 0.05 |
| 47 | -28.47 | 6.96 | 0.00 | 0.02 | 0.28 |
| 49 | -4.67 | 6.65 | 0.00 | 0.00 | 0.26 |
| 53 | -4.78 | 6.83 | 0.08 | 0.00 | 0.03 |
| 54 | -21.29 | 6.94 | 0.04 | 0.06 | 0.03 |
| 55 | -16.53 | 6.81 | 0.05 | 0.37 | 0.05 |
| 57 | 2.99 | 6.83 | 0.00 | 0.00 | 0.00 |
| 59 | 5.16 | 6.85 | 0.06 | 0.01 | 0.06 |
| 61 | -12.50 | 7.10 | 0.03 | 0.03 | 0.04 |
| 62 | -20.17 | 7.03 | 0.02 | 0.01 | 0.04 |

## Appendix E: Wasteload Allocations

**Table E1**. Allocated Metal Effluent Concentrations for Mining Point Sources in Paint Creek Watershed.

| NPDES Permit | Outlet | Sub-WS | Wasteload Allocations Iron (mg/L) | Wasteload Allocations Manganese (mg/L) | Wasteload Allocations Aluminum (mg/L) | Wasteload Allocations Iron (Mg/yr) | Wasteload Allocations Manganese (Mg/yr) | Wasteload Allocations Aluminum (Mg/yr) |
|---|---|---|---|---|---|---|---|---|
| WV0057011 | 18 | 8 | 3.20 | 2.00 | 1.25 | 0.091383 | 0.057114 | 0.035696 |
| WV1009311 | 4 | 9 | 3.20 | 2.00 | 4.30 | 0.013124 | 0.008203 | 0.017635 |
| WV1009311 | 5 | 9 | 3.20 | 2.00 | 4.30 | 0.016405 | 0.010253 | 0.022044 |
| WV1015257 | 2 | 10 | 3.20 | 2.00 | 2.71 | 0.272940 | 0.170587 | 0.231146 |
| WV1009320 | 2 | 11 | 3.20 | 2.00 | 4.30 | 0.003079 | 0.001924 | 0.004137 |
| WV1009320 | 3 | 11 | 3.20 | 2.00 | 4.30 | 0.001539 | 0.000962 | 0.002069 |
| WV1009311 | 6 | 15 | 2.00 | 1.13 | 0.86 | 0.017590 | 0.009938 | 0.007564 |
| WV1014951 | 3 | 23 | 3.20 | 2.00 | 1.81 | 0.039962 | 0.024977 | 0.022604 |
| WV1014951 | 4 | 23 | 3.20 | 2.00 | 1.81 | 0.001537 | 0.000961 | 0.000869 |
| WV1014951 | 42 | 23 | 3.20 | 2.00 | 1.81 | 0.013833 | 0.008646 | 0.007824 |
| WV1014951 | 5 | 23 | 3.20 | 2.00 | 1.81 | 0.015370 | 0.009606 | 0.008694 |
| WV1014951 | 6 | 23 | 3.20 | 2.00 | 1.81 | 0.003074 | 0.001921 | 0.001739 |
| WV1014951 | 7 | 23 | 3.20 | 2.00 | 1.81 | 0.015370 | 0.009606 | 0.008694 |
| WV1014951 | 8 | 23 | 3.20 | 2.00 | 1.81 | 0.006148 | 0.003843 | 0.003478 |
| WV1014951 | 9 | 26 | 3.20 | 2.00 | 4.30 | 0.009222 | 0.005764 | 0.012392 |
| WV1014951 | 35 | 27 | 1.83 | 1.05 | 0.75 | 0.015826 | 0.009080 | 0.006486 |
| WV1014951 | 36 | 27 | 1.83 | 1.05 | 0.75 | 0.000879 | 0.000504 | 0.000360 |
| WV1014951 | 37 | 27 | 1.83 | 1.05 | 0.75 | 0.007913 | 0.004540 | 0.003243 |
| WV1014951 | 14 | 27 | 1.83 | 1.05 | 0.75 | 0.005275 | 0.003027 | 0.002162 |
| WV1014951 | 39 | 27 | 1.83 | 1.05 | 0.75 | 0.005275 | 0.003027 | 0.002162 |
| WV1014951 | 40 | 27 | 1.83 | 1.05 | 0.75 | 0.001758 | 0.001009 | 0.000721 |
| WV1014951 | 45 | 27 | 1.83 | 1.05 | 0.75 | 0.009671 | 0.005549 | 0.003964 |
| WV1014951 | 32 | 27 | 1.83 | 1.05 | 0.75 | 0.008165 | 0.004685 | 0.003346 |
| WV1014951 | 43 | 27 | 1.83 | 1.05 | 0.75 | 0.226799 | 0.130130 | 0.092950 |
| WV1014951 | 10 | 27 | 1.83 | 1.05 | 0.75 | 0.010548 | 0.006052 | 0.004323 |
| WV1014951 | 11 | 27 | 1.83 | 1.05 | 0.75 | 0.001758 | 0.001009 | 0.000720 |
| WV1014951 | 12 | 27 | 1.83 | 1.05 | 0.75 | 0.014943 | 0.008574 | 0.006124 |
| WV1014951 | 13 | 27 | 1.83 | 1.05 | 0.75 | 0.000879 | 0.000504 | 0.000360 |
| WV1014951 | 41 | 27 | 1.83 | 1.05 | 0.75 | 0.004395 | 0.002522 | 0.001801 |
| WV1002368 | 1 | 28 | 3.20 | 2.00 | 4.30 | 0.542277 | 0.338923 | 0.728685 |
| WV1002368 | 4 | 28 | 3.20 | 2.00 | 4.30 | 0.136721 | 0.085451 | 0.183719 |
| WV1002368 | 5 | 28 | 3.20 | 2.00 | 4.30 | 0.015362 | 0.009601 | 0.020643 |
| WV1002368 | 2 | 28 | 3.20 | 2.00 | 4.30 | 0.044550 | 0.027844 | 0.059864 |
| WV1002368 | 3 | 28 | 3.20 | 2.00 | 4.30 | 0.102925 | 0.064328 | 0.138306 |
| WV0028452 | 9 | 31 | 1.86 | 1.05 | 0.91 | 0.001784 | 0.001007 | 0.000873 |
| WV0028452 | 12 | 31 | 1.86 | 1.05 | 0.91 | 0.000892 | 0.000504 | 0.000436 |
| WV0028452 | 13 | 31 | 1.86 | 1.05 | 0.91 | 0.000892 | 0.000504 | 0.000436 |
| WV0028452 | 15 | 31 | 1.86 | 1.05 | 0.91 | 0.008922 | 0.005036 | 0.004365 |
| WV0028452 | 8 | 31 | 1.86 | 1.05 | 0.91 | 0.001784 | 0.001007 | 0.000873 |
| WV0028452 | 14 | 31 | 1.86 | 1.05 | 0.91 | 0.008922 | 0.005036 | 0.004365 |
| WV0028452 | 3 | 31 | 1.86 | 1.05 | 0.91 | 0.005353 | 0.003022 | 0.002619 |
| WV1014951 | 31 | 31 | 1.86 | 1.05 | 0.91 | 0.008029 | 0.004533 | 0.003928 |
| WV1014951 | 33 | 31 | 1.86 | 1.05 | 0.91 | 0.008029 | 0.004533 | 0.003928 |
| WV1014951 | 38 | 31 | 1.86 | 1.05 | 0.91 | 0.008029 | 0.004533 | 0.003928 |
| WV0028452 | 5 | 31 | 1.86 | 1.05 | 0.91 | 0.000892 | 0.000504 | 0.000436 |
| WV0028452 | 1 | 31 | 1.86 | 1.05 | 0.91 | 0.004461 | 0.002518 | 0.002182 |

**Table E1**. Allocated Metal Effluent Concentrations for Mining Point Sources in Paint Creek Watershed.

| NPDES Permit | Outlet | Sub-WS | Wasteload Allocations Iron (mg/L) | Wasteload Allocations Manganese (mg/L) | Wasteload Allocations Aluminum (mg/L) | Wasteload Allocations Iron (Mg/yr) | Wasteload Allocations Manganese (Mg/yr) | Wasteload Allocations Aluminum (Mg/yr) |
|---|---|---|---|---|---|---|---|---|
| WV0028452 | 4 | 31 | 1.86 | 1.05 | 0.91 | 0.016059 | 0.009066 | 0.007857 |
| WV0028452 | 6 | 31 | 1.86 | 1.05 | 0.91 | 0.003569 | 0.002015 | 0.001746 |
| WV1012487 | 160 | 35 | 3.20 | 2.00 | 2.05 | 0.003440 | 0.002150 | 0.002204 |
| WV1012487 | 161 | 35 | 3.20 | 2.00 | 2.05 | 0.055034 | 0.034396 | 0.035256 |
| WV1012487 | 156 | 35 | 3.20 | 2.00 | 2.05 | 0.003440 | 0.002150 | 0.002204 |
| WV1012487 | 157 | 35 | 3.20 | 2.00 | 2.05 | 0.030957 | 0.019348 | 0.019832 |
| WV1012487 | 158 | 35 | 3.20 | 2.00 | 2.05 | 0.030957 | 0.019348 | 0.019832 |
| WV1012487 | 159 | 35 | 3.20 | 2.00 | 2.05 | 0.008599 | 0.005374 | 0.005509 |
| WV1012487 | 162 | 35 | 3.20 | 2.00 | 2.05 | 0.006879 | 0.004300 | 0.004407 |
| WV1012487 | 163 | 35 | 3.20 | 2.00 | 2.05 | 0.001720 | 0.001075 | 0.001102 |
| WV1012487 | 164 | 35 | 3.20 | 2.00 | 2.05 | 0.029237 | 0.018273 | 0.018730 |
| WV1012487 | 165 | 35 | 3.20 | 2.00 | 2.05 | 0.010319 | 0.006449 | 0.006611 |
| WV1012487 | 166 | 35 | 3.20 | 2.00 | 2.05 | 0.003440 | 0.002150 | 0.002204 |
| WV1012487 | 151 | 35 | 3.20 | 2.00 | 2.05 | 0.008599 | 0.005374 | 0.005509 |
| WV1012487 | 152 | 35 | 3.20 | 2.00 | 2.05 | 0.001720 | 0.001075 | 0.001102 |
| WV1012487 | 153 | 35 | 3.20 | 2.00 | 2.05 | 0.001720 | 0.001075 | 0.001102 |
| WV1012487 | 154 | 35 | 3.20 | 2.00 | 2.05 | 0.005159 | 0.003225 | 0.003305 |
| WV1012487 | 9 | 40 | 1.57 | 2.00 | 4.30 | 0.012657 | 0.016123 | 0.034665 |
| WV1012487 | 10 | 40 | 1.57 | 2.00 | 4.30 | 0.004219 | 0.005374 | 0.011555 |
| WV1012487 | 64 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 7 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 8 | 40 | 1.57 | 2.00 | 4.30 | 0.002531 | 0.003225 | 0.006933 |
| WV1012487 | 32 | 40 | 1.57 | 2.00 | 4.30 | 0.008438 | 0.010749 | 0.023110 |
| WV1012487 | 33 | 40 | 1.57 | 2.00 | 4.30 | 0.024470 | 0.031172 | 0.067019 |
| WV1012487 | 34 | 40 | 1.57 | 2.00 | 4.30 | 0.007594 | 0.009674 | 0.020799 |
| WV1012487 | 65 | 40 | 1.57 | 2.00 | 4.30 | 0.001688 | 0.002150 | 0.004622 |
| WV1012487 | 3 | 40 | 1.57 | 2.00 | 4.30 | 0.004219 | 0.005374 | 0.011555 |
| WV1012487 | 4 | 40 | 1.57 | 2.00 | 4.30 | 0.001688 | 0.002150 | 0.004622 |
| WV1012487 | 5 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 6 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 35 | 40 | 1.57 | 2.00 | 4.30 | 0.006750 | 0.008599 | 0.018488 |
| WV1012487 | 36 | 40 | 1.57 | 2.00 | 4.30 | 0.004219 | 0.005374 | 0.011555 |
| WV1012487 | 37 | 40 | 1.57 | 2.00 | 4.30 | 0.014344 | 0.018273 | 0.039287 |
| WV1012487 | 38 | 40 | 1.57 | 2.00 | 4.30 | 0.003375 | 0.004300 | 0.009244 |
| WV1012487 | 39 | 40 | 1.57 | 2.00 | 4.30 | 0.003375 | 0.004300 | 0.009244 |
| WV1012487 | 40 | 40 | 1.57 | 2.00 | 4.30 | 0.004219 | 0.005374 | 0.011555 |
| WV1012487 | 41 | 40 | 1.57 | 2.00 | 4.30 | 0.189008 | 0.240775 | 0.517665 |
| WV1012487 | 42 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 66 | 40 | 1.57 | 2.00 | 4.30 | 0.001688 | 0.002150 | 0.004622 |
| WV1012487 | 67 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 68 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 69 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 70 | 40 | 1.57 | 2.00 | 4.30 | 0.013501 | 0.017198 | 0.036976 |
| WV1012487 | 71 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 72 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 73 | 40 | 1.57 | 2.00 | 4.30 | 0.019407 | 0.024722 | 0.053153 |
| WV1012487 | 74 | 40 | 1.57 | 2.00 | 4.30 | 0.001688 | 0.002150 | 0.004622 |
| WV1012487 | 75 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |

**Table E1**. Allocated Metal Effluent Concentrations for Mining Point Sources in Paint Creek Watershed.

| NPDES Permit | Outlet | Sub-WS | Wasteload Allocations Iron (mg/L) | Wasteload Allocations Manganese (mg/L) | Wasteload Allocations Aluminum (mg/L) | Wasteload Allocations Iron (Mg/yr) | Wasteload Allocations Manganese (Mg/yr) | Wasteload Allocations Aluminum (Mg/yr) |
|---|---|---|---|---|---|---|---|---|
| WV1012487 | 76 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 77 | 40 | 1.57 | 2.00 | 4.30 | 0.001688 | 0.002150 | 0.004622 |
| WV1012487 | 78 | 40 | 1.57 | 2.00 | 4.30 | 0.021938 | 0.027947 | 0.060086 |
| WV1012487 | 79 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 80 | 40 | 1.57 | 2.00 | 4.30 | 0.006750 | 0.008599 | 0.018488 |
| WV1012487 | 81 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 82 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 83 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 84 | 40 | 1.57 | 2.00 | 4.30 | 0.017720 | 0.022573 | 0.048531 |
| WV1012487 | 85 | 40 | 1.57 | 2.00 | 4.30 | 0.004219 | 0.005374 | 0.011555 |
| WV1012487 | 86 | 40 | 1.57 | 2.00 | 4.30 | 0.004219 | 0.005374 | 0.011555 |
| WV1012487 | 87 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 88 | 40 | 1.57 | 2.00 | 4.30 | 0.001688 | 0.002150 | 0.004622 |
| WV1012487 | 89 | 40 | 1.57 | 2.00 | 4.30 | 0.012657 | 0.016123 | 0.034665 |
| WV1012487 | 90 | 40 | 1.57 | 2.00 | 4.30 | 0.007594 | 0.009674 | 0.020799 |
| WV1012487 | 109 | 40 | 1.57 | 2.00 | 4.30 | 0.001688 | 0.002150 | 0.004622 |
| WV1012487 | 110 | 40 | 1.57 | 2.00 | 4.30 | 0.000844 | 0.001075 | 0.002311 |
| WV1012487 | 19 | 42 | 3.20 | 2.00 | 4.30 | 0.003988 | 0.002492 | 0.005359 |
| WV1012487 | 20 | 42 | 3.20 | 2.00 | 4.30 | 0.005982 | 0.003739 | 0.008038 |
| WV1012487 | 22 | 42 | 3.20 | 2.00 | 4.30 | 0.015951 | 0.009969 | 0.021434 |
| WV1012487 | 57 | 42 | 3.20 | 2.00 | 4.30 | 0.003988 | 0.002492 | 0.005359 |
| WV1012487 | 58 | 42 | 3.20 | 2.00 | 4.30 | 0.001994 | 0.001246 | 0.002679 |
| WV1012487 | 59 | 42 | 3.20 | 2.00 | 4.30 | 0.039878 | 0.024924 | 0.053586 |
| WV1012487 | 60 | 42 | 3.20 | 2.00 | 4.30 | 0.012039 | 0.007524 | 0.016177 |
| WV1012487 | 104 | 42 | 3.20 | 2.00 | 4.30 | 0.005982 | 0.003739 | 0.008038 |
| WV1012487 | 105 | 42 | 3.20 | 2.00 | 4.30 | 0.015951 | 0.009969 | 0.021434 |
| WV1012487 | 106 | 42 | 3.20 | 2.00 | 4.30 | 0.030957 | 0.019348 | 0.041598 |
| WV1012487 | 108 | 42 | 3.20 | 2.00 | 4.30 | 0.005159 | 0.003225 | 0.006933 |
| WV1012487 | 115 | 42 | 3.20 | 2.00 | 4.30 | 0.257212 | 0.160758 | 0.345629 |
| WV1012487 | 167 | 42 | 3.20 | 2.00 | 4.30 | 0.001994 | 0.001246 | 0.002679 |
| WV1012487 | 21 | 42 | 3.20 | 2.00 | 4.30 | 0.001994 | 0.001246 | 0.002679 |
| WV1012487 | 61 | 42 | 3.20 | 2.00 | 4.30 | 0.001720 | 0.001075 | 0.002311 |
| WV1012487 | 62 | 42 | 3.20 | 2.00 | 4.30 | 0.001720 | 0.001075 | 0.002311 |
| WV1012487 | 16 | 42 | 3.20 | 2.00 | 4.30 | 0.010319 | 0.006449 | 0.013866 |
| WV1012487 | 17 | 42 | 3.20 | 2.00 | 4.30 | 0.001720 | 0.001075 | 0.002311 |
| WV1012487 | 13 | 42 | 3.20 | 2.00 | 4.30 | 0.010319 | 0.006449 | 0.013866 |
| WV1012487 | 15 | 42 | 3.20 | 2.00 | 4.30 | 0.013759 | 0.008599 | 0.018488 |
| WV1012487 | 11 | 42 | 3.20 | 2.00 | 4.30 | 0.001720 | 0.001075 | 0.002311 |
| WV1012487 | 12 | 42 | 3.20 | 2.00 | 4.30 | 0.015478 | 0.009674 | 0.020799 |
| WV1012487 | 14 | 42 | 3.20 | 2.00 | 4.30 | 0.018918 | 0.011824 | 0.025421 |
| WV1012487 | 63 | 42 | 3.20 | 2.00 | 4.30 | 0.013759 | 0.008599 | 0.018488 |
| WV1012487 | 111 | 42 | 3.20 | 2.00 | 4.30 | 0.005159 | 0.003225 | 0.006933 |
| WV1002066 | 1 | 45 | 1.80 | 1.04 | 0.79 | 0.011216 | 0.006480 | 0.004922 |
| WV1002066 | 2 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1002066 | 3 | 45 | 1.80 | 1.04 | 0.79 | 0.009870 | 0.005703 | 0.004332 |
| WV1002066 | 6 | 45 | 1.80 | 1.04 | 0.79 | 0.006729 | 0.003888 | 0.002953 |
| WV1012487 | 43 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 145 | 45 | 1.80 | 1.04 | 0.79 | 0.005608 | 0.003240 | 0.002461 |

**Table E1**. Allocated Metal Effluent Concentrations for Mining Point Sources in Paint Creek Watershed.

| NPDES Permit | Outlet | Sub-WS | Wasteload Allocations Iron (mg/L) | Wasteload Allocations Manganese (mg/L) | Wasteload Allocations Aluminum (mg/L) | Wasteload Allocations Iron (Mg/yr) | Wasteload Allocations Manganese (Mg/yr) | Wasteload Allocations Aluminum (Mg/yr) |
|---|---|---|---|---|---|---|---|---|
| WV1012487 | 149 | 45 | 1.80 | 1.04 | 0.79 | 0.011216 | 0.006480 | 0.004922 |
| WV1012487 | 46 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 47 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1002066 | 4 | 45 | 1.80 | 1.04 | 0.79 | 0.006729 | 0.003888 | 0.002953 |
| WV1002066 | 5 | 45 | 1.80 | 1.04 | 0.79 | 0.006729 | 0.003888 | 0.002953 |
| WV1012487 | 4 | 45 | 1.80 | 1.04 | 0.79 | 0.001935 | 0.001118 | 0.000849 |
| WV1012487 | 5 | 45 | 1.80 | 1.04 | 0.79 | 0.000967 | 0.000559 | 0.000425 |
| WV1012487 | 31 | 45 | 1.80 | 1.04 | 0.79 | 0.004486 | 0.002592 | 0.001969 |
| WV1012487 | 44 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1012487 | 45 | 45 | 1.80 | 1.04 | 0.79 | 0.003365 | 0.001944 | 0.001477 |
| WV1012487 | 146 | 45 | 1.80 | 1.04 | 0.79 | 0.005608 | 0.003240 | 0.002461 |
| WV1012487 | 150 | 45 | 1.80 | 1.04 | 0.79 | 0.003365 | 0.001944 | 0.001477 |
| WV1012487 | 27 | 45 | 1.80 | 1.04 | 0.79 | 0.005608 | 0.003240 | 0.002461 |
| WV1012487 | 48 | 45 | 1.80 | 1.04 | 0.79 | 0.008973 | 0.005184 | 0.003938 |
| WV1012487 | 49 | 45 | 1.80 | 1.04 | 0.79 | 0.004486 | 0.002592 | 0.001969 |
| WV1012487 | 91 | 45 | 1.80 | 1.04 | 0.79 | 0.011216 | 0.006480 | 0.004922 |
| WV1012487 | 92 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1012487 | 93 | 45 | 1.80 | 1.04 | 0.79 | 0.006729 | 0.003888 | 0.002953 |
| WV1012487 | 147 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 148 | 45 | 1.80 | 1.04 | 0.79 | 0.011216 | 0.006480 | 0.004922 |
| WV1012487 | 29 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1012487 | 50 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 94 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 114 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 30 | 45 | 1.80 | 1.04 | 0.79 | 0.022431 | 0.012960 | 0.009845 |
| WV1012487 | 51 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 52 | 45 | 1.80 | 1.04 | 0.79 | 0.007851 | 0.004536 | 0.003446 |
| WV1012487 | 53 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 54 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1012487 | 95 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 96 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 97 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1012487 | 98 | 45 | 1.80 | 1.04 | 0.79 | 0.006729 | 0.003888 | 0.002953 |
| WV1012487 | 99 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1012487 | 100 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1012487 | 103 | 45 | 1.80 | 1.04 | 0.79 | 0.003365 | 0.001944 | 0.001477 |
| WV1012487 | 113 | 45 | 1.80 | 1.04 | 0.79 | 0.004486 | 0.002592 | 0.001969 |
| WV1012487 | 25 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 55 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1012487 | 23 | 45 | 1.80 | 1.04 | 0.79 | 0.007851 | 0.004536 | 0.003446 |
| WV1012487 | 24 | 45 | 1.80 | 1.04 | 0.79 | 0.010094 | 0.005832 | 0.004430 |
| WV1012487 | 26 | 45 | 1.80 | 1.04 | 0.79 | 0.002243 | 0.001296 | 0.000984 |
| WV1012487 | 56 | 45 | 1.80 | 1.04 | 0.79 | 0.001122 | 0.000648 | 0.000492 |
| WV1012487 | 112 | 45 | 1.80 | 1.04 | 0.79 | 0.003365 | 0.001944 | 0.001477 |
| WV1002074 | 26 | 46 | 3.20 | 2.00 | 4.30 | 0.012235 | 0.007647 | 0.016440 |
| WV1002074 | 27 | 46 | 3.20 | 2.00 | 4.30 | 0.002719 | 0.001699 | 0.003653 |
| WV1002074 | 28 | 46 | 3.20 | 2.00 | 4.30 | 0.032626 | 0.020391 | 0.043841 |
| WV1002074 | 29 | 46 | 3.20 | 2.00 | 4.30 | 0.271881 | 0.169926 | 0.365340 |

**Table E1**. Allocated Metal Effluent Concentrations for Mining Point Sources in Paint Creek Watershed.

| NPDES Permit | Outlet | Sub-WS | Wasteload Allocations Iron (mg/L) | Wasteload Allocations Manganese (mg/L) | Wasteload Allocations Aluminum (mg/L) | Wasteload Allocations Iron (Mg/yr) | Wasteload Allocations Manganese (Mg/yr) | Wasteload Allocations Aluminum (Mg/yr) |
|---|---|---|---|---|---|---|---|---|
| WV1002074 | 32 | 46 | 3.20 | 2.00 | 4.30 | 0.004078 | 0.002549 | 0.005480 |
| WV1019317 | 1 | 46 | 3.20 | 2.00 | 4.30 | 0.004078 | 0.002549 | 0.005480 |
| WV1002074 | 30 | 46 | 3.20 | 2.00 | 4.30 | 0.259647 | 0.162279 | 0.348900 |
| WV1002074 | 31 | 46 | 3.20 | 2.00 | 4.30 | 0.014953 | 0.009346 | 0.020094 |
| WV1014820 | 1 | 48 | 3.20 | 2.00 | 4.30 | 0.010875 | 0.006797 | 0.014614 |
| WV0092142 | 2 | 52 | 2.43 | 1.54 | 1.15 | 0.032871 | 0.020832 | 0.015556 |
| WV0092142 | 1 | 52 | 2.43 | 1.54 | 1.15 | 0.002529 | 0.001602 | 0.001197 |

**Appendix F: Load Allocations.**

Table F1. Non-Point Source Acid Load Allocated for each Sub-Watershed.

| Stream Name | Sub-WS Number | Baseline Acid Load (Mg/yr) | Allocated Acid Load (Mg/yr) | Relative Acid Load Reduction |
|---|---|---|---|---|
| Paint Creek below Banner Hollow | 1 | 0.0000 | 0.0000 | 0% |
| Banner Hollow | 2 | -26.8459 | -26.8459 | 0% |
| Paint Creek above Banner Hollow and below Fourmile Fork | 3 | 0.0000 | 0.0000 | 0% |
| Fourmile Fork | 4 | -16.9135 | -16.9228 | 0% |
| Paint Creek above Fourmile Fork and below Ash Branch | 5 | 0.0000 | 0.0000 | 0% |
| Ash Branch | 6 | -65.7423 | -65.7450 | 0% |
| Paint Creek above Ash Branch and below Toms Branch | 7 | 0.0000 | 0.0000 | 0% |
| Toms Branch | 8 | 0.0000 | 0.0000 | 0% |
| Paint Creek above Toms Branch and below Tenmile Branch | 9 | 0.0000 | 0.0000 | 0% |
| Long Branch | 10 | 52.0795 | 0.0547 | 100% |
| Tenmile Branch above Long Branch and below Unnamed Tributary | 11 | 71.0703 | 0.0000 | 100% |
| Unnamed Tributary of Tenmile Branch | 12 | -19.5621 | -19.5621 | 0% |
| Tenmile Branch above Unnamed Tributary | 13 | -20.7396 | -20.7396 | 0% |
| Paint Creek above Tenmile Branch and below Laurel Branch | 14 | 0.0000 | 0.0000 | 0% |
| Laurel Branch | 15 | 1829.8900 | 591.6960 | 68% |
| Paint Creek above Laurel Branch and below Unnamed Branch | 16 | 0.0000 | 0.0000 | 0% |
| Unnamed Branch of Paint Creek | 17 | -0.7872 | -0.7872 | 0% |
| Paint Creek above Unnamed Branch and below Hickory Camp Branch | 18 | 0.0000 | 0.0000 | 0% |
| Hickory Camp Branch | 19 | -1.4327 | -1.4399 | 1% |
| Paint Creek above Hickory Camp Branch and below Cedar Creek | 20 | 0.0000 | 0.0000 | 0% |
| Cedar Creek | 21 | 6.8210 | 0.6322 | 91% |
| Paint Creek above Cedar Creek and below Fifteenmile Creek | 22 | 116.3010 | 0.0000 | 100% |
| Fifteenmile Creek | 23 | -10.1211 | -10.1211 | 0% |
| Paint Creek above Fifteenmile Creek and below Unnamed Tributary | 24 | 0.0000 | 0.0000 | 0% |
| Spring Branch | 25 | 7.3589 | 0.1004 | 99% |
| Paint Creek above Unnamed Tributary and below Skitter Creek | 26 | 0.0000 | 0.0000 | 0% |
| Skitter Creek | 27 | -7.1882 | -7.1882 | 0% |
| Paint Creek above Skitter Creek and below Rattlesnake Run | 28 | 0.0000 | 0.0000 | 0% |
| Rattlesnake Run | 29 | 0.0000 | 0.0000 | 0% |
| Paint Creek above Rattlesnake Run and below Milburn Creek | 30 | 0.0000 | 0.0000 | 0% |
| Milburn Creek | 31 | -0.1830 | -0.1830 | 0% |

| Table F1. Non-Point Source Acid Load Allocated for each Sub-Watershed. | | | | | | |
|---|---|---|---|---|---|---|
| | Sub- | Baseline | Allocated | Relative | | |
| Stream | WS | Acid Load | Acid Load | Acid Load | | |
| Name | Number | (Mg/yr) | (Mg/yr) | Reduction | | |
| Paint Creek above Milburn Creek and below Lykins Creek | 32 | 0.0000 | 0.0000 | 0% | | |
| Lykins Creek | 33 | 0.0000 | 0.0000 | 0% | | |
| Paint Creek above Lykins Creek and below Bishop Fork | 34 | 0.0000 | 0.0000 | 0% | | |
| Bishop Fork | 35 | -12.0386 | -12.0387 | 0% | | |
| Paint Creek above Bishop Fork and below Mossy Creek | 36 | 0.0000 | 0.0000 | 0% | | |
| Mossy Creek below Lick Fork | 37 | 0.0000 | 0.0000 | 0% | | |
| Lick Fork | 38 | -6.4823 | -6.4823 | 0% | | |
| Mossy Creek above Lick Fork | 39 | -31.4732 | -31.4732 | 0% | | |
| Paint Creek above Mossy Creek and below Plum Orchard Creek | 40 | 0.0000 | 0.0000 | 0% | | |
| Plum Orchard Creek | 41 | -22.7147 | -22.7147 | 0% | | |
| Paint Creek above Plum Orchard Creek and below Horse Creek | 42 | 0.0000 | 0.0000 | 0% | | |
| Horse Creek | 43 | -7.8379 | -7.8421 | 0% | | |
| Paint Creek above Horse Creek and below Town Creek | 44 | 0.0000 | 0.0000 | 0% | | |
| Town Creek | 45 | -5.0554 | -5.0554 | 0% | | |
| Paint Creek above Town Creek and below Packs Branch | 46 | 0.0000 | 0.0000 | 0% | | |
| Packs Branch | 47 | -21.5686 | -21.5686 | 0% | | |
| Paint Creek above Packs Branch and below Dixons Branch | 48 | 0.0000 | 0.0000 | 0% | | |
| Dixons Branch | 49 | -12.0616 | -12.0616 | 0% | | |
| Paint Creek above Dixons Branch and below Sand Branch | 50 | 0.0000 | 0.0000 | 0% | | |
| Sand Branch below North Sand Branch | 51 | 0.0000 | 0.0000 | 0% | | |
| North Sand Branch below Maple Fork | 52 | 0.0000 | 0.0000 | 0% | | |
| Maple Fork | 53 | -21.3956 | -21.3956 | 0% | | |
| North Sand Branch above Maple Fork | 54 | -58.9777 | -58.9777 | 0% | | |
| South Sand Branch | 55 | -41.2540 | -41.2540 | 0% | | |
| Paint Creek above Sand Branch and below Laurel Branch | 56 | 0.0000 | 0.0000 | 0% | | |
| Laurel Branch | 57 | -2.9969 | -3.2137 | 7% | | |
| Paint Creek above Laurel Branch and below Davis Branch | 58 | 0.0000 | 0.0000 | 0% | | |
| Davis Branch | 59 | -0.4560 | -0.4560 | 0% | | |
| Paint Creek above Davis Branch and below Lefthand Fork | 60 | 0.0000 | 0.0000 | 0% | | |
| Lefthand Fork | 61 | -14.9771 | -14.9771 | 0% | | |
| Paint Creek above Lefthand Fork | 62 | -148.4890 | -148.4890 | 0% | | |

Table F2. Non-Point Source Aluminum Load Allocated for each Sub-Watershed.

| Stream Name | Sub-WS Number | Baseline Aluminum Load (Mg/yr) | Allocated Aluminum Load (Mg/yr) | Relative Aluminum Load Reduction |
|---|---|---|---|---|
| Paint Creek below Banner Hollow | 1 | 0.6293 | 0.5657 | 10% |
| Banner Hollow | 2 | 0.1462 | 0.0457 | 69% |
| Paint Creek above Banner Hollow and below Fourmile Fork | 3 | 0.0012 | 0.0012 | 0% |
| Fourmile Fork | 4 | 0.0106 | 0.0106 | 0% |
| Paint Creek above Fourmile Fork and below Ash Branch | 5 | 2.2317 | 2.2317 | 0% |
| Ash Branch | 6 | 0.5519 | 0.0063 | 99% |
| Paint Creek above Ash Branch and below Toms Branch | 7 | 0.2631 | 0.2631 | 0% |
| Toms Branch | 8 | 0.1637 | 0.0164 | 90% |
| Paint Creek above Toms Branch and below Tenmile Branch | 9 | 0.4725 | 0.3911 | 17% |
| Long Branch | 10 | 11.7132 | 0.0079 | 100% |
| Tenmile Branch above Long Branch and below Unnamed Tributary | 11 | 0.0226 | 0.0117 | 48% |
| Unnamed Tributary of Tenmile Branch | 12 | 0.4968 | 0.0165 | 97% |
| Tenmile Branch above Unnamed Tributary | 13 | 1.3679 | 0.0304 | 98% |
| Paint Creek above Tenmile Branch and below Laurel Branch | 14 | 0.0012 | 0.0012 | 0% |
| Laurel Branch | 15 | 1.3277 | 0.0133 | 99% |
| Paint Creek above Laurel Branch and below Unnamed Branch | 16 | 0.0027 | 0.0027 | 0% |
| Unnamed Branch of Paint Creek | 17 | 0.1820 | 0.0029 | 98% |
| Paint Creek above Unnamed Branch and below Hickory Camp Branch | 18 | 0.0001 | 0.0001 | 0% |
| Hickory Camp Branch | 19 | 0.5227 | 0.0044 | 99% |
| Paint Creek above Hickory Camp Branch and below Cedar Creek | 20 | 0.1293 | 0.1293 | 0% |
| Cedar Creek | 21 | 1.4855 | 0.0135 | 99% |
| Paint Creek above Cedar Creek and below Fifteenmile Creek | 22 | 4.0173 | 0.9552 | 76% |
| Fifteenmile Creek | 23 | 0.0039 | 0.0039 | 0% |
| Paint Creek above Fifteenmile Creek and below Unnamed Tributary | 24 | 0.1362 | 0.1362 | 0% |
| Spring Branch | 25 | 1.6824 | 0.0112 | 99% |
| Paint Creek above Unnamed Tributary and below Skitter Creek | 26 | 0.0023 | 0.0023 | 0% |
| Skitter Creek | 27 | 0.1014 | 0.0101 | 90% |
| Paint Creek above Skitter Creek and below Rattlesnake Run | 28 | 0.0042 | 0.0042 | 0% |
| Rattlesnake Run | 29 | 0.0029 | 0.0029 | 0% |
| Paint Creek above Rattlesnake Run and below Milburn Creek | 30 | 0.0017 | 0.0017 | 0% |
| Milburn Creek | 31 | 0.7586 | 0.0091 | 99% |

Table F2. Non-Point Source Aluminum Load Allocated for each Sub-Watershed.

| Stream Name | Sub-WS Number | Baseline Aluminum Load (Mg/yr) | Allocated Aluminum Load (Mg/yr) | Relative Aluminum Load Reduction | |
|---|---|---|---|---|---|
| Paint Creek above Milburn Creek and below Lykins Creek | 32 | 0.0012 | 0.0012 | 0% | |
| Lykins Creek | 33 | 0.0021 | 0.0021 | 0% | |
| Paint Creek above Lykins Creek and below Bishop Fork | 34 | 0.0041 | 0.0041 | 0% | |
| Bishop Fork | 35 | 0.8125 | 0.0041 | 99% | |
| Paint Creek above Bishop Fork and below Mossy Creek | 36 | 0.0001 | 0.0001 | 0% | |
| Mossy Creek below Lick Fork | 37 | 0.0146 | 0.0146 | 0% | |
| Lick Fork | 38 | 0.2920 | 0.0092 | 97% | |
| Mossy Creek above Lick Fork | 39 | 0.3587 | 0.0145 | 96% | |
| Paint Creek above Mossy Creek and below Plum Orchard Creek | 40 | 0.0068 | 0.0068 | 0% | |
| Plum Orchard Creek | 41 | 0.1739 | 0.1739 | 0% | |
| Paint Creek above Plum Orchard Creek and below Horse Creek | 42 | 0.0031 | 0.0031 | 0% | |
| Horse Creek | 43 | 0.0982 | 0.0066 | 93% | |
| Paint Creek above Horse Creek and below Town Creek | 44 | 0.0004 | 0.0004 | 0% | |
| Town Creek | 45 | 0.1612 | 0.0055 | 97% | |
| Paint Creek above Town Creek and below Packs Branch | 46 | 0.2679 | 0.2679 | 0% | |
| Packs Branch | 47 | 0.3545 | 0.0603 | 83% | |
| Paint Creek above Packs Branch and below Dixons Branch | 48 | 0.0098 | 0.0098 | 0% | |
| Dixons Branch | 49 | 0.1810 | 0.0067 | 96% | |
| Paint Creek above Dixons Branch and below Sand Branch | 50 | 0.0032 | 0.0032 | 0% | |
| Sand Branch below North Sand Branch | 51 | 0.0017 | 0.0017 | 0% | |
| North Sand Branch below Maple Fork | 52 | 0.0007 | 0.0007 | 0% | |
| Maple Fork | 53 | 0.2997 | 0.0093 | 97% | |
| North Sand Branch above Maple Fork | 54 | 0.7000 | 0.0117 | 98% | |
| South Sand Branch | 55 | 0.1944 | 0.0351 | 82% | |
| Paint Creek above Sand Branch and below Laurel Branch | 56 | 0.0006 | 0.0006 | 0% | |
| Laurel Branch | 57 | 0.1057 | 0.0040 | 96% | |
| Paint Creek above Laurel Branch and below Davis Branch | 58 | 0.0019 | 0.0019 | 0% | |
| Davis Branch | 59 | 0.0755 | 0.0055 | 93% | |
| Paint Creek above Davis Branch and below Lefthand Fork | 60 | 0.0023 | 0.0023 | 0% | |
| Lefthand Fork | 61 | 0.1188 | 0.0048 | 96% | |
| Paint Creek above Lefthand Fork | 62 | 1.3090 | 0.0073 | 99% | |

Table F3. Non-Point Source Iron Load Allocated for each Sub-Watershed.

| Stream Name | Sub-WS Number | Baseline Iron Load (Mg/yr) | Allocated Iron Load (Mg/yr) | Relative Iron Load Reduction |
|---|---|---|---|---|
| Paint Creek below Banner Hollow | 1 | 0.4210 | 0.4210 | 0% |
| Banner Hollow | 2 | 0.0016 | 0.0016 | 0% |
| Paint Creek above Banner Hollow and below Fourmile Fork | 3 | 0.0003 | 0.0003 | 0% |
| Fourmile Fork | 4 | 0.0022 | 0.0022 | 0% |
| Paint Creek above Fourmile Fork and below Ash Branch | 5 | 1.4644 | 1.4644 | 0% |
| Ash Branch | 6 | 0.0013 | 0.0013 | 0% |
| Paint Creek above Ash Branch and below Toms Branch | 7 | 0.0370 | 0.0370 | 0% |
| Toms Branch | 8 | 0.0008 | 0.0008 | 0% |
| Paint Creek above Toms Branch and below Tenmile Branch | 9 | 0.1726 | 0.0517 | 70% |
| Long Branch | 10 | 0.3620 | 0.3620 | 0% |
| Tenmile Branch above Long Branch and below Unnamed Tributary | 11 | 0.0168 | 0.0168 | 0% |
| Unnamed Tributary of Tenmile Branch | 12 | 0.3510 | 0.0694 | 80% |
| Tenmile Branch above Unnamed Tributary | 13 | 1.0326 | 0.0820 | 92% |
| Paint Creek above Tenmile Branch and below Laurel Branch | 14 | 0.5219 | 0.0052 | 99% |
| Laurel Branch | 15 | 0.0005 | 0.0005 | 0% |
| Paint Creek above Laurel Branch and below Unnamed Branch | 16 | 1.1239 | 0.0112 | 99% |
| Unnamed Branch of Paint Creek | 17 | 0.0002 | 0.0002 | 0% |
| Paint Creek above Unnamed Branch and below Hickory Camp Branch | 18 | 0.0595 | 0.0006 | 99% |
| Hickory Camp Branch | 19 | 0.0084 | 0.0084 | 0% |
| Paint Creek above Hickory Camp Branch and below Cedar Creek | 20 | 0.3926 | 0.0039 | 99% |
| Cedar Creek | 21 | 0.3094 | 0.0307 | 90% |
| Paint Creek above Cedar Creek and below Fifteenmile Creek | 22 | 3.2347 | 0.3409 | 89% |
| Fifteenmile Creek | 23 | 0.0012 | 0.0008 | 35% |
| Paint Creek above Fifteenmile Creek and below Unnamed Tributary | 24 | 0.6187 | 0.0062 | 99% |
| Spring Branch | 25 | 0.0823 | 0.0082 | 90% |
| Paint Creek above Unnamed Tributary and below Skitter Creek | 26 | 0.9533 | 0.0095 | 99% |
| Skitter Creek | 27 | 0.0190 | 0.0019 | 90% |
| Paint Creek above Skitter Creek and below Rattlesnake Run | 28 | 1.7645 | 0.0176 | 99% |
| Rattlesnake Run | 29 | 0.0006 | 0.0006 | 0% |
| Paint Creek above Rattlesnake Run and below Milburn Creek | 30 | 0.7163 | 0.0072 | 99% |
| Milburn Creek | 31 | 0.3602 | 0.0360 | 90% |

Table F3. Non-Point Source Iron Load Allocated for each Sub-Watershed.

| Stream Name | Sub-WS Number | Baseline Iron Load (Mg/yr) | Allocated Iron Load (Mg/yr) | Relative Iron Load Reduction | | |
|---|---|---|---|---|---|---|
| Paint Creek above Milburn Creek and below Lykins Creek | 32 | 0.4916 | 0.0049 | 99% | | |
| Lykins Creek | 33 | 0.0004 | 0.0004 | 0% | | |
| Paint Creek above Lykins Creek and below Bishop Fork | 34 | 1.7046 | 0.0170 | 99% | | |
| Bishop Fork | 35 | 0.0673 | 0.0673 | 0% | | |
| Paint Creek above Bishop Fork and below Mossy Creek | 36 | 0.0398 | 0.0004 | 99% | | |
| Mossy Creek below Lick Fork | 37 | 2.6755 | 0.0307 | 99% | | |
| Lick Fork | 38 | 0.0162 | 0.0162 | 0% | | |
| Mossy Creek above Lick Fork | 39 | 1.9549 | 0.0150 | 99% | | |
| Paint Creek above Mossy Creek and below Plum Orchard Creek | 40 | 2.8793 | 0.0288 | 99% | | |
| Plum Orchard Creek | 41 | 1.2028 | 0.0097 | 99% | | |
| Paint Creek above Plum Orchard Creek and below Horse Creek | 42 | 1.3197 | 0.0013 | 100% | | |
| Horse Creek | 43 | 0.3990 | 0.0070 | 98% | | |
| Paint Creek above Horse Creek and below Town Creek | 44 | 0.1571 | 0.0016 | 99% | | |
| Town Creek | 45 | 0.2238 | 0.0023 | 99% | | |
| Paint Creek above Town Creek and below Packs Branch | 46 | 4.7979 | 0.0023 | 100% | | |
| Packs Branch | 47 | 1.3108 | 0.1227 | 91% | | |
| Paint Creek above Packs Branch and below Dixons Branch | 48 | 4.1438 | 0.0020 | 100% | | |
| Dixons Branch | 49 | 2.3775 | 0.0066 | 100% | | |
| Paint Creek above Dixons Branch and below Sand Branch | 50 | 1.3565 | 0.0094 | 99% | | |
| Sand Branch below North Sand Branch | 51 | 0.0003 | 0.0003 | 0% | | |
| North Sand Branch below Maple Fork | 52 | 0.0001 | 0.0001 | 0% | | |
| Maple Fork | 53 | 0.9272 | 0.0019 | 100% | | |
| North Sand Branch above Maple Fork | 54 | 1.2595 | 0.0059 | 100% | | |
| South Sand Branch | 55 | 18.5526 | 0.1169 | 99% | | |
| Paint Creek above Sand Branch and below Laurel Branch | 56 | 0.0997 | 0.0010 | 99% | | |
| Laurel Branch | 57 | 0.4359 | 0.0080 | 98% | | |
| Paint Creek above Laurel Branch and below Davis Branch | 58 | 0.3291 | 0.0033 | 99% | | |
| Davis Branch | 59 | 0.3475 | 0.0548 | 84% | | |
| Paint Creek above Davis Branch and below Lefthand Fork | 60 | 0.4138 | 0.0005 | 100% | | |
| Lefthand Fork | 61 | 0.3816 | 0.0010 | 100% | | |
| Paint Creek above Lefthand Fork | 62 | 2.6677 | 0.0015 | 100% | | |

# Appendix G

## Holistic Watershed Approach Protocol for Integrated Watershed Characterization

**Holistic Watershed Approach Protocol for Integrated Watershed Characterization**

**(Adapted from Vukovich S.M. and G.E. Adolfson. 2001. Holistic Watershed Approach Protocol for Integrated Watershed Characterizations. Integrated Decision Making for Watershed Management Symposium. Washington, D.C.)**

## Background

Integrated watershed characterizations produce better environmental data and information to make more informed decisions about where and how we invest our resources toward watershed management of mine drainage pollution and associated Total Maximum Daily Load (TMDL) implementation. Involving local, state, and federal agencies; industry; academia; and the public in planning and sampling for watershed characterizations, has led to effective protection, restoration, and enhancement of the ecological integrity of water quality and quantity. Time, costs, knowledge, skills, and abilities are some of the limiting factors when attempting to perform these tasks separately for the desired ecological integrity. Inconsistencies in planning, sampling, and data collection methodologies create quality assurance and quality control concerns. A standard operating procedure, or protocol, eliminates these inconsistencies. Implementation of a protocol, in an integrated fashion, reduces limitations and promotes outreach, education, and training, as well as improves knowledge, skills, and abilities. The West Virginia Division of Environmental Protection's Stream Restoration Group currently implements a Holistic Watershed Approach Protocol involving diverse stakeholders in planning and sampling for integrated watershed characterizations in six of West Virginia's thirty-two hydrologic regions. The Protocol is a dynamic document continually evolving to accommodate multiple applications and satisfy specific needs of diverse stakeholders.

## Methodology

When a watershed is designated for watershed characterization to determine impairment from mine drainage pollution discharges, the *study area* watershed boundaries are determined and stakeholders are notified. Watersheds are defined based on the USGS-developed hydrologic unit cataloging (HUC) system. Stakeholder involvement, spearheaded by watershed organizations, is incorporated into all aspects of watershed characterizations, including: restoration, protection, and enhancement.

With the assistance of the stakeholders, a *comprehensive sampling network* is established, mapped, and staked. This *network* includes sampling locations that divide the main-stem into segments representing changes in water quality from upstream to downstream. Sampling locations at the mouth of all main-stem tributaries along with extensive sampling locations throughout the tributary stream reach are also included. Water quality and quantity measurements are obtained three to six times, spanning a range of hydrologic and climatologic conditions. Benthic macroinvertebrate surveys and fish surveys at selected locations are also collected during this time period.

If the watershed is large and dendritic, additional sampling of a *streamlined sampling network* is conducted. This consists of sampling locations of the main-stem and all the main-stem tributaries at the mouth locations only.
The environmental data and information is reviewed and main-stem tributaries are prioritized according to degree of impairment. A *focus area sampling network* of a selected main-stem tributary is then established and mapped. The *network* consists of sampling locations at the pollution sources as well as at various locations throughout the main-stem tributary reach. Sampling locations are determined by researching existing data and field reviewing the area for all sources of mine drainage pollution discharges. As with the *comprehensive sampling network*, water quality and quantity measurements are obtained three to six times, spanning a range of hydrologic and climatologic conditions. Benthic macroinvertebrate surveys are also collected during this time period.

The data is reviewed and utilized for: establishing the impact of the mine drainage pollution sources to the *focus area* tributaries, selecting the most feasible pollution sources within the *focus area* to address, and identifying the best available technology for the abatement or treatment of the pollution sources.

Following mine drainage pollution remediation of selected project sites within the *focus area*, a *post construction sampling network* is established. It consists of the same *focus area* locations sampled prior to construction, in addition to the treated discharges resulting from the installation of any mine drainage pollution abatement technologies. All new sampling site coordinates are obtained and mapped. Three to six water quality and quantity sampling sweeps are conducted spanning a range of hydrologic and climatologic conditions. Benthic macroinvertebrate surveys are also collected during this time period.

This process continues until all *focus areas* in the initial *study area* have been addressed, and all feasible treatment or abatement technologies applied. At that time, three to six water quality and quantity sampling sweeps of the initial *comprehensive sampling network* are conducted spanning a range of hydrologic and climatologic conditions. Benthic macroinvertebrate surveys and fish surveys are also collected during this time period.

Results are analyzed and a report prepared evaluating the effect of the abatement or treatment technologies on the mine drainage pollution sources and their receiving streams.

Once implemented, the Protocol is a perpetual cycle with many overlapping process steps. The Protocol outline and a process flowchart is presented below:

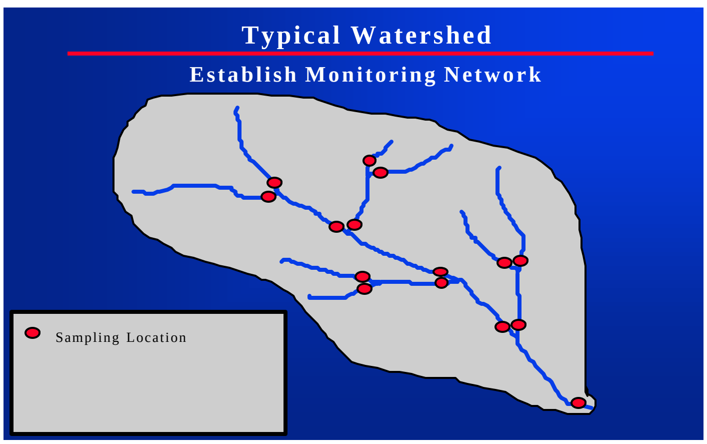
**Holistic Watershed Approach Protocol**

**I. Define the *study area* and stakeholders.**

- Select main-stem stream.
- Delineate watershed boundary.
- Foster Stakeholders.

**II. Establish *comprehensive sampling network* within the *study area*.**

- Select and number stream sampling stations utilizing USGS 7.5 Minute Topographic Quadrangle Maps and field reconnaissance.
    - Select main-stem stream sampling stations representing main-stem stream segments.
    - Select all main-stem tributary sampling stations at the mouth locations and at extensive locations throughout the main-stem tributary stream reach.




**III. Geo-reference *comprehensive sampling network* for input into Geographical Information Systems (GIS).**

**IV. Implement sampling sweeps of the *comprehensive sampling network*.**

- Conduct *Water Quality Study* sweeps three to six times spanning a range of hydrologic and climatologic conditions.
    - Perform water sample collection.
        - Collect stream water sample for laboratory analysis employing “grab” sample method.

        - Perform field measurements.
            - Obtain *in situ* water quality measurements at all sampling stations.
            - Obtain stream flow.
    - Conduct *Biological and Physical Study* one time between April and November.
        - Perform stream habitat assessments and qualitative benthic macroinvertebrate surveys at all stream sampling stations.
        - Perform fish survey at selective stream sampling stations only.

**V. Review all data collected. (If watershed is large and dendritic, continue or otherwise skip to IX.)**

- Analyze changes in tributary and main-stem stream segments and compare tributaries.
    - Represent *Water Quality Study* data graphically.
    - Compare *Biological and Physical Study* data.

**VI. Establish *streamlined sampling network* within the *comprehensive sampling network*.**

- Select and number stream sampling stations.
    - Select main-stem stream sampling stations representing main-stem stream segments.
    - Select all main-stem tributary sampling stations at the mouth locations only.

**VII. Implement sampling sweeps of *streamlined sampling network*.**

- Conduct *Water Quality Study* sweeps three to six times spanning a range of hydrologic and climatologic conditions.
    - Perform water sample collection.
        - Collect stream water sample for laboratory analysis employing "grab" sample method.
    - Perform field measurements.
        - Obtain *in situ* water quality measurements at all sampling stations.
        - Obtain stream flow.

**VIII. Review all data collected.**

- Analyze changes in tributary and main-stem stream segments and compare tributaries.
    - Represent *Water Quality Study* data graphically.
    - Compare *Biological and Physical Study* data.

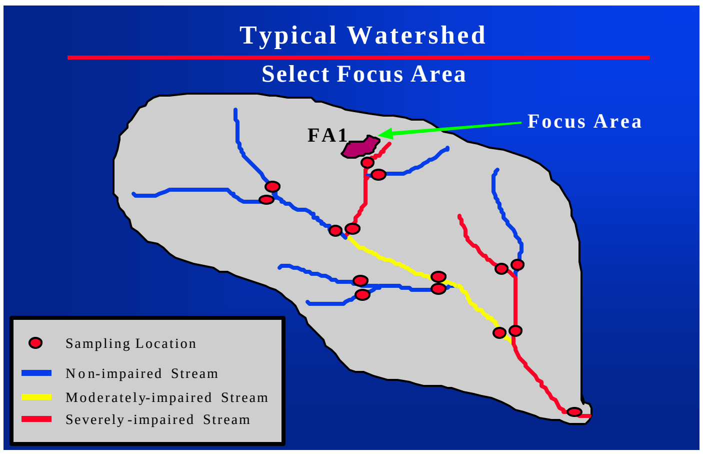
- Compare main-stem tributaries with respect to degree of impairment.

**IX. Define *focus study area*.**

- Select impaired tributary within *comprehensive sampling network* and determine watershed boundary.

**X. Establish *focus area sampling network* within the *focus study area*.**

- Locate mine drainage pollution discharge sampling stations within impaired tributary watershed.
  - Research existing data.
  - Field review entire impaired tributary watershed.
- Select impaired tributary sampling stations at mouth location and at extensive locations throughout the tributary stream reach, including stations upstream and downstream of mine drainage pollution discharge influx.
- Select receiving stream sampling stations upstream and downstream of the confluence with the impaired tributary.




**XI. Geo-reference *focus area sampling network* for input into Geographical Information Systems (GIS).**

**XII. Implement sampling sweeps of *focus area sampling network*.**

- Conduct *Water Quality Study* sweeps two to three times spanning a range of hydrologic and climatologic conditions.
  - Perform water sample collection.
    - Collect stream water sample for laboratory analysis employing “grab” sample method.

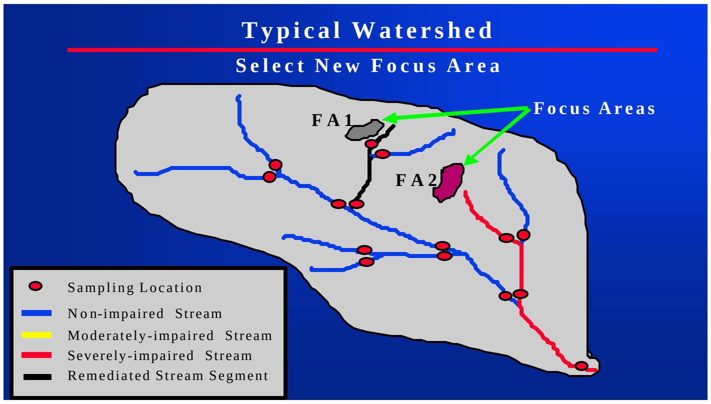
    - Collect pollution source water sample at origin.  (When several sources co-mingle, it is necessary to collect a sample of the combined discharge.)
  - Perform field measurements.
    - Obtain *in situ* water quality measurements at all sampling stations.
    - Obtain stream flow.
- Conduct *Biological and Physical Study* one time between April and November.
  - Perform stream habitat assessments and qualitative benthic macroinvertebrate surveys upstream and downstream of mine drainage pollution discharge project areas.

**XIII. Review all data collected.**

- Analyze *focus area sampling* network data.
  - Determine extent of impairment mine drainage pollution discharge contributes to the *focus area* impaired tributaries.
  - Determine site-specific mine drainage pollution discharge treatment technology for the sources at each project area.
    - Evaluate chemical suitability of selected mine drainage pollution discharge treatment technology.
    - Evaluate physical suitability of selected mine drainage pollution discharge treatment technology.
  - Determine in-stream mine drainage pollution discharge treatment technology for stream benefits in addition to, or in lieu of site-specific pollution discharge treatment.

**XIV. Modify *focus area sampling network*.  [If additional data is or may be required to support pre construction design(s), repeat XII through XIII.]**

- Cease sampling of any portion of project for which polluted water abatement appears infeasible.
- Incorporate sampling of any additional *focus area(s)* mine drainage pollution discharges found following completion of **XII**.




**XV. Report findings.**

- Prepare preliminary pre-design *Water Quality Study* report.

**Implementation**

**XVI. Establish *post construction focus area sampling network* when mine drainage pollution discharge treatment is complete in the *focus study area*. (If initial *study area* contains other *focus study area(s)* that have not been addressed, repeat IX through XV, otherwise continue.)**

- Locate constructed mine drainage pollution discharge treatment systems within treatment project boundaries.
  - Field review mine drainage pollution discharge treatment project site.
- Select and number stream sampling stations throughout *focus study area*.
  - Select the previously impaired tributary sampling stations at mouth location and at extensive locations throughout the tributary stream reach, including stations upstream and downstream of mine drainage pollution discharge treatment project influx.
  - Select receiving stream sampling stations upstream and downstream of the confluence with the previously impaired tributary.

**XVII. Geo-reference *post construction focus area sampling network* for input into Geographical Information Systems (GIS).**

**XVIII. Implement sampling sweeps of *post construction focus area sampling network*.**

- Conduct *Water Quality Study* sweeps monthly during the first year period; quarterly during the second year period; and semiannually

during the third and every subsequent year period spanning a range of hydrologic and climatologic conditions.
  - Perform water sample collection.
    - Collect stream water sample for laboratory analysis employing “grab” sample method.
    - Collect untreated source water sample at origin if possible.
    - Collect treated source water sample at mine drainage pollution discharge treatment system outflow.
  - Perform field measurements.
    - Obtain *in situ* water quality measurements at all sampling stations.
    - Obtain stream flow.
- Conduct *Biological and Physical Study* one time between April and November, at least one year after completion of project construction.
  - Perform stream habitat assessments and qualitative benthic macroinvertebrate surveys upstream and downstream of mine drainage pollution discharge treatment project influx.

**XIX. Implement sampling sweeps of the *comprehensive sampling network*. (If mine drainage pollution discharge treatment is complete throughout initial *study area* continue.)**

- Conduct *Water Quality Study* sweeps three to six times spanning a range of hydrologic and climatologic conditions.
  - Perform water sample collection.
    - Collect stream water sample for laboratory analysis employing “grab” sample method.
  - Perform field measurements.
    - Obtain *in situ* water quality measurements at all sampling stations.
    - Obtain stream flow.
- Conduct *Biological and Physical Study* one time between April and November.
  - Perform stream habitat assessments and qualitative benthic macroinvertebrate surveys at all stream sampling stations.
  - Perform fish survey at selective stream sampling stations only.

**XX. Review all data collected.**

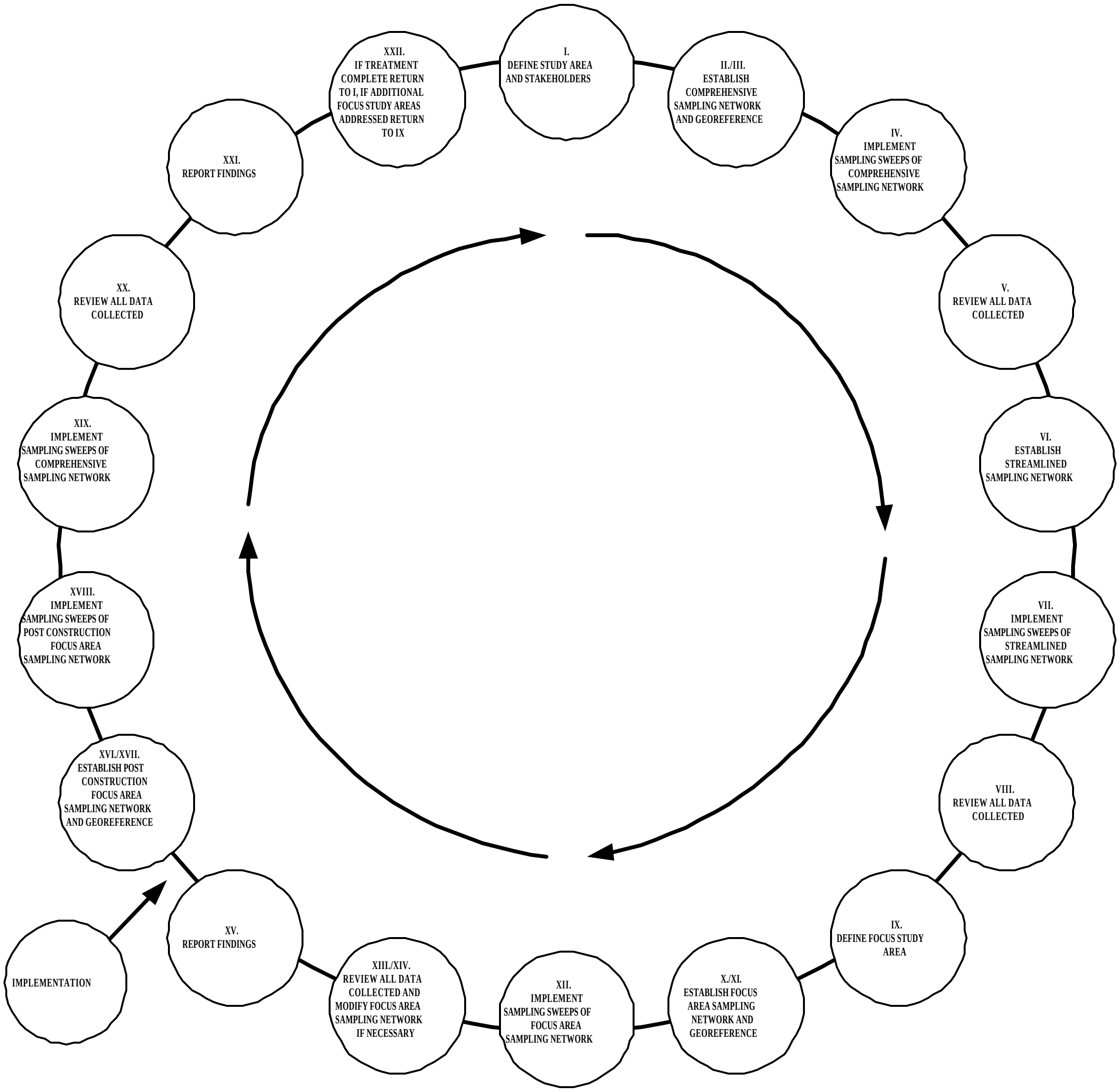
- Analyze changes in stream water quality.
- Analyze effectiveness and efficiency of constructed mine drainage pollution discharge treatment systems.
- Determine the effect of constructed mine drainage pollution discharge treatment systems on the mine drainage pollution discharges, *focus area sampling networks*, and *comprehensive sampling network*.

**XXI. Report findings**

- Prepare final post construction *Water Quality Study* report.

**XXII. If mine drainage pollution discharge treatment is complete throughout the *study area*, return to I. If additional *focus study areas* will be addressed within the *study area*, return to IX.**

# Holistic Watershed Approach Protocol




Holistic Watershed Approach Protocol